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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS. XV - VARIOUS CONTOUR MODIFICATIONS OF A 0.30-AIRFOIL-CHORD PLAIN FLAP ON AN NACA 66(215)-014 AIRFOIL

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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS. XX - VARIOUS CONTOUR MODIFICATIONS OF A 0.30-AIRFOIL-CHORD PLAIN FLAP ON AN NACA 66(215)-014 AIRFOIL

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SUMMARY

Force-test measurements in two-dimensional flow have been made in the NACA 4- by 6-foot vertical tunnel to determine the aerodynamic characteristics of an NACA 66(215)-014 airfoil equipped with true-contour, straight-contour, and beveled-trailing-edge flaps having chords 30 percent of the airfoil chord. The results are presented in the form of aerodynamic section characteristics for several flap deflections and for a sealed and unsealed gap at the flap nose.

The slope of the lift curve, the effectiveness of the flap, and the negative slopes of the hinge-moment curves generally decreased as the trailing-edge angle was increased, as the gap at the flap nose was opened, and as roughness was added to the leading edge of the airfoil.

The aerodynamic center of lift caused by changing angle of attack moved forward as the trailing-edge angle was increased and as roughness was added to the airfoil leading edge. The aerodynamic center of lift caused by changing flap deflection tended to move forward when the trailing-edge angle was increased and, when roughness was added to the airfoil leading edge, tended to move rearward for the true-contour flap, to remain unchanged for the straight-contour flap, and to move forward for the beveled-trailing-edge flap.

The effects of beveled trailing edges on the characteristics of a plain flap on a low-drag airfoil were not

significantly different from the effects previously noted for similar modifications on conventional airfoils.

INTRODUCTION

An extensive two-dimensional-flow investigation of the aerodynamic section characteristics of airfoils with flaps has been undertaken by the NACA to determine the types of flap arrangement best suited for use as control surfaces and to supply experimental data for design purposes. The investigation has included modifications of flap-nose shape, balance length, and gap size on a 9-percent thick low-drag airfoil and on 9- and 15-percent-thick conventional airfoils. Other modifications have included the use of a straight-contour flap and a beveled-trailing-edge flap. The results of some of these investigations were reported in references 1 to 5. Reference 6 has used the trailing-edge angle of the beveled-trailing-edge flap as a basis for correlation.

High-speed airplanes require the use of airfoil sections with low peak pressures, such as low-drag sections, for tail surfaces to alleviate the danger of shock stall. In order to extend airfoil profile alterations to low-drag airfoil contours, tests have been made of the NACA 66(215)-014 airfoil equipped with true-contour, flat-contour, and beveled-trailing-edge flaps. Throughout the present paper, the flap having the same contour as the trailing edge of the basic airfoil will be referred to as the true-contour flap, the flap having a contour formed by straight lines drawn from the flap nose arc to the trailing edge as the straight-contour flap, and the flap formed by thickening and beveling the trailing-edge portion of a straight-contour flap as the beveled-trailing-edge flap.

APPARATUS AND MODEL

The tests were made in the NACA 4- by 6-foot vertical tunnel described in reference 7. The test section of this tunnel has been converted from the original open, circular, 5-foot diameter jet to a closed, rectangular, 4- by 6-foot throat for force tests of models in two-dimensional flow. A three-component balance system has been installed in the tunnel to measure lift, drag, and pitching moments. The hinge moments of the flap were measured from a special torque-rod balance built into the model.

The 2-foot-chord by 4-foot-span model (fig. 1) was built of laminated mahogany to the NACA 66(215)-014 profile. (See table I.) The airfoil was equipped with a true-contour flap and a beveled-trailing-edge flap with chords 30 percent of the airfoil chord (0.30c). The cusp of the true-contour flap was filled in with plasticine to form the straight-contour flap used in part of the tests. The nose radius of each flap was approximately one-half the airfoil thickness at the flap hinge axis, and the flap gap was 0.002c. For the sealed-gap tests, a rubber sheet was connected between the nose of the flap and the airfoil.

The model, when mounted in the tunnel, completely spanned the test section and was attached to the balance frame by torque tubes that extended through the sides of the tunnel. The angle of attack was set from outside the tunnel by rotating the torque tubes with an electric drive.

TESTS

The tests were made at dynamic pressures of 11.25 and 15.00 pounds per square foot, which correspond, respectively, to airspeeds of about 66 and 76 miles per hour at standard sea-level conditions. The effective Reynolds numbers of the tests were approximately 2,400,000 and 2,760,000. The effective Reynolds number is the product of the test Reynolds number and the turbulence factor, which is 1.93 for the 4- by 6-foot vertical tunnel.

The three flap contours tested were set at flap deflections from 0° to 30° in increments to 5°, including and additional deflection of 2°, with the gap both sealed and unsealed. For each flap setting, the values of lift, drag, pitching moment, and flap hinge moment were read throughout the angle-of-attack range from negative stall to positive stall. All readings were taken at increments of angle of attack of 2°, except near the stall where the increment was reduced to 1°.

Force tests were also made at an angle of attack of 0°, at flap deflections from 0° to 30° in increments of 5° (including an additional deflection of 2°) in order to provide a check for the tests previously mentioned and to obtain data for measuring some of the parameters without cross-plotting.

In order to determine the effect of a fixed transition point near the leading edge on the aerodynamic characteristics, force tests were also made with surface roughness extending back approximately 2.7 inches (0.11c) from the airfoil leading edge. The roughness consisted of carborundum particles of the size and distribution referred to as standard roughness in reference 8.

The accuracy of the data is indicated by the deviation from zero of the lift and moment coefficients at an angle of attack of 0° with the flap neutral. The maximum error in effective angle of attack at zero lift appeared to be about ±0.2°. Flap deflections were set to within ±0.2°. Tunnel corrections, experimentally determined in the 4- by 6-foot vertical tunnel, were applied only to lift. The hinge moments are probably slightly higher than would be obtained in free air and, consequently, the values presented are considered conservative. (See reference 9.) The increments of drag should be reasonably independent of tunnel effect, although the absolute values are subject to unknown tunnel and turbulence corrections.

SYMBOLS

The coefficients and symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient about quarter-chord point of airfoil (m/qc^2)

c_{h_f} flap section hinge-moment coefficient (h_f/qc_f^2)

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h_f flap section hinge moment

c chord of basic airfoil with flap neutral

c_f flap chord

q dynamic pressure

and

α_o angle of attack for airfoil of infinite aspect ratio, degrees

δ_f flap deflection with respect to airfoil, degrees

ϕ trailing edge angle - included between sides which form trailing edge of flap, degrees.

R_e effective Reynolds number

PRESENTATION OF RESULTS

The aerodynamic section characteristics of the NACA 66(215)-014 airfoil for a gap of 0.002c and for the gap sealed are presented in figures 2 and 3, respectively, for the 0.30c true-contour flap, in figures 4 and 5, respectively, for the 0.30c straight-contour flap, and in figures 6 and 7, respectively, for the 0.30c beveled-trailing-edge flap.

A comparison of the aerodynamic section characteristics at zero flap deflection with smooth and roughened leading edge for the true-contour, straight-contour, and beveled-trailing-edge flaps is shown in figure 8 with a gap of 0.002c and in figure 9 with the gap sealed. The variation of the aerodynamic section characteristics with flap deflection for the true contour, straight-contour, and beveled-trailing-edge flaps with a smooth and roughened leading edge at zero angle of attack is shown in figures 10 and 11 with a gap of 0.002c and with the gap sealed, respectively.

Increments of section profile-drag coefficient caused by deflecting the flaps are given in figure 12 for the true-contour flap, in figure 13 for the straight-contour flap, and in figure 14 for the beveled-trailing-edge flap. Figure 15 shows the effect of Reynolds number on the airfoil with the true-contour flap at zero deflection with the gap sealed.

The flap hinge-moment parameters $\left(\partial c_{h_f}/\partial \alpha_0\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_0}$ are shown in figure 16 as functions of the trailing-edge angle for a gap of 0.002c and for the gap sealed with a smooth and roughened leading edge. The various parameters for the true-contour, straight-contour, and beveled-trailing-edge flaps, which are presented for comparison in table II, are the values of slopes measured at an angle of attack and a flap deflection of 0°.

DISCUSSION OF RESULTS

Lift

General shape of lift curves.- The lift curves of the straight-contour or beveled-trailing-edge flaps for various flap deflections and for the gap open (figs. 4 and 6) or for the gap closed (figs. 5 and 7) have the same general shape as the lift curves of the true-contour flap for the gap open (fig. 2) or for the gap closed (fig. 3). The gap-open and gap-sealed conditions have different flap deflection ranges where the lift curves approach the linear conditions. For the gap-open conditions, some nonlinearily occurs for the 10° and 15° flap deflections; whereas, for the gap-sealed condition, this nonlinearity is most noticeable for the 15° and 20° flap deflections. As the trailing-edge angle increases, the range of flap deflections over which this nonlinearity occurs tends to become larger when the gap is sealed and to remain the same when the gap is open.

The angle of attack at which the airfoil stalled tended to increase slightly as the trailing-edge angle increased with the gap open but was approximately the same with the gap sealed. A comparison of figures 2 and 3 with the data of reference 1 indicates that the lift curves for various deflections of the true-contour flap for both the sealed and unsealed gap on the NACA 66(215)-014 airfoil are more linear and indicate stall at greater angles of attack than those of the NACA 66-009 airfoil.

Slope of lift curves.- The slope of the lift curve $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ for the true-contour flap was larger than that for the straight-contour or beveled-trailing-edge flap with the sealed or unsealed gap. (See table II.) The decrease in $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ for the three flap contours that occurred with increasing trailing-edge angle may be attributed to the increased thickness of the after portion of the airfoil, which caused an increased deviation in flow from the theoretical flow for thin airfoils. A decrease in $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ also occurred for the three flap contours when the gap was unsealed. This trend agrees qualitatively with the results for the NACA 0009, 0015, and 66-009 airfoils (references 1 to 5).

Effectiveness of flap.- The effectiveness of the flaps $\left(\partial \alpha_0/\partial \delta_f\right)_{c_l}$ was greatest for the true-contour flap and was approximately the same with the gap both sealed and unsealed. As the trailing-edge angle increased, the effectiveness decreased; and unsealing the gap further reduced the flap effectiveness (table II).

With the gap unsealed, all flaps tested were effective in producing positive increments of lift at all positive flap deflections within the unstalled range of angle of attack. The flap effectiveness at zero angle of attack and small flap deflections was greater with the gap sealed than with the gap unsealed, but the increments of lift for the high flap deflections with the gap sealed were very small or zero in part of the negative angle-of-attack range. Although a drop in effectiveness occurred at high flap deflections at negative angles of attack, the drop in effectiveness with flap deflection at the positive angle of attack was not so pronounced for the NACA 66(215)-014 airfoil as for the NACA 66-009 airfoil (reference 1) and 0015 airfoil (reference 5).

Slope of lift curves with controls free.- The parameter $(\partial c_l/\partial \alpha_0)_{c_{h_f}} = 0$ (table II) is a measure of control-free stability. The slope of the control-free lift curve was less than that of the control-fixed lift curve for the true-contour flap with the gap either sealed or unsealed. For the straight-contour flap the slope of the lift curve with control free was smaller than with control fixed for the sealed gap; whereas no change occurred for the open gap. The slope of the control-free lift curve was larger than that of the control-fixed lift curve for the beveled-trailing-edge flap, being greater when the gap was unsealed than when sealed. Comparison of the data for the three flap contours shows an increase in $(\partial c_l/\partial \alpha_0)_{c_{h_f}} = 0$ with trailing-edge angle.

It should be noted that these statements are based on slope values measured over a small angular range and their use is therefore limited to stability calculations and other applications which are concerned only with small changes in angle of attack and deflection.

Effect of leading-edge roughness.- The effect of roughness on the airfoil leading edge was to decrease the slope of the airfoil lift curves and the effectiveness of the true-contour, straight-contour, and beveled-trailing-edge flaps for the gap both sealed and unsealed. (See table II.) The presence of roughness on the airfoil leading edge did not change the tendency of the open gap and the increased trailing-edge angle to reduce the slope of the airfoil lift curve and the flap effectiveness.

With controls free the slopes of the lift curves were larger with a roughened leading edge than with a smooth leading edge in all cases except that of the true-contour flap with gap sealed and the beveled-trailing-edge flap with gap unsealed. For the beveled-trailing-edge flap with gap unsealed the presence of roughness resulted in an unstable condition because both $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ were positive.

The lift coefficient increased relatively linearly with the flap deflections above 10° with either smooth or roughened leading edge when the gap was sealed or unsealed (figs. 10 and 11). The general effect of roughness, however, was to reduce the lift coefficient at a given flap deflection and to reduce the maximum lift coefficient.

Effect of Reynolds number.- An increase in effective Reynolds number from approximately 2,400,000 to 2,760,000 increased the maximum lift coefficient from 1.06 to 1.13 at positive angles of attack and from -1.01 to -1.20 at negative angles of attack for the NACA 66(215)-014 airfoil with a true-contour flap at $\delta_f = 0^\circ$ with the gap sealed. (See fig. 15.) Increasing the effective Reynolds number caused a slight increase in the slope of the lift curve. The differences in the angles of attack for zero lift for the two tests is within the limits noted previously under "Tests" and is probably the result of errors in setting the angle of attack or flap deflection.

Hinge Moment of Flap

General shape of hinge-moment curves.- The curves of flap section hinge moment plotted against angle of attack (figs. 2 to 7) were not unusual except for the breaks that occurred at the intermediate and high flap deflections. These breaks, generally larger with the gap sealed than with the gap unsealed, were probably the result of flow separation over the flap.

Slope of hinge-moment curves.- The hinge-moment parameters for the three flap contours with the gap sealed and unsealed are given in table II. Because of the nonlinearity of the hinge-moment curves over most of the angle-of-attack range, the parameter $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ was measured at $\delta_f = 0^\circ$ and $\alpha_o = 0^\circ$ over the linear range previously mentioned. Although this range is small, these values can be used for comparing the three flap contours and for stability computations; however, for a complete comparison the entire set of hinge-moment curves must be taken into consideration.

The measured slope $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ was zero for the straight-contour flap with the gap unsealed; however, for the gap both sealed and unsealed, $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ was negative for the true-contour flap and was positive, showing an overbalance, for the beveled-trailing-edge flap. (See figs. 8 and 9.) The value $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ was more positive for the flaps with the larger trailing-edge angles. This trend agrees qualitatively with the data of reference 4, but the actual value of the change is larger than that indicated by the curves of reference 6.

Values of the parameter $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ (figs. 10 and 11) were measured at flap deflections from 0° to 5° because of the nonlinearity of the flap section hinge-moment curves throughout the flap deflection range. An increase in trailing-edge angle produces a decrease in the negative value of $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ for the gap sealed or unsealed (table II). This trend also agrees with the data of reference 4 but the actual values are again larger than those indicated by the curves of reference 6.

Effect of leading-edge roughness.- The effect of leading edge roughness on the variation of $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ with trailing-edge angle and gap condition for the 0.30c flaps on the NACA 66(215)-014 airfoil (fig. 16) was to make both $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ more positive. The presence of leading-edge roughness did not alter the general tendency of $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ to become more positive with increases in trailing-edge angle and with unsealing the gap.

Effect of Reynolds number.- An increase in effective Reynolds number from approximately 2,400,000 to 2,760,000 slightly increased the negative value of $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$

for the true-contour flap at $\delta_f = 0^\circ$ with the gap sealed (fig. 15). The difference in the values of the hinge-moment coefficient at $\alpha_o = 0^\circ$ probably resulted from errors in setting the angle of attack and flap deflection.

Pitching Moment

The values of the parameters $(\partial c_m/\partial c_l)_{\alpha_o}$ and $(\partial c_m/\partial c_l)_{\delta_f}$, shown in table II, give the position of the aerodynamic center with respect to the quarter-chord point. When the lift was varied by changing the angle of attack at a flap deflection of 0°, the aerodynamic center of the smooth airfoil with a sealed gap was at 0.25c for the true-contour flap, 0.22c for the straight-contour flap, and 0.20c for the beveled trailing-edge flap. This trend agrees qualitatively with the results in reference 4. With roughness on the leading edge, the aerodynamic center moved slightly forward to 0.24c for the true-contour flap, to 0.21c for the straight-contour flap, and to 0.19c for the beveled-trailing-edge flap. Unsealing the gap generally had little effect on the position of the aerodynamic center. Increasing the effective Reynolds number had very little effect on the aerodynamic center of the airfoil with the sealed true-contour flap at $\delta_f = 0^\circ$ (fig. 15).

The following table gives the position of the aerodynamic center of lift due to flap deflection:

	Aerodynamic center					
Leading edge	True-contour flap		Straight-contour flap		Beveled-trailing-edge flap	
	0.002c gap	Sealed gap	0.002c gap	Sealed gap	0.002c gap	Sealed gap
Smooth	0.43c	0.41c	0.43c	0.42c	0.40c	0.41c
Rough	.46c	.44c	.43c	.42c	.38c	.38c

With roughness on the leading edge, the aerodynamic center of lift caused by flap deflection moved rearward about 0.03c for the true-contour flap, remained unchanged for the straight-contour flap, and moved 0.02c to 0.03c forward for the beveled-trailing-edge flap. The position of the aerodynamic center of lift caused by flap deflections is a function of the aspect ratio (reference 10) and moves toward the trailing edge as the aspect ratio decreases. It can be seen that, if the aerodynamic-center positions are plotted against $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ there is a general trend for the aerodynamic centers to move forward as the slopes of the hinge-moment curves become more positive.

Drag

Because the turbulence of the 4- by 6-foot vertical tunnel made it impossible for the low-drag condition to be realized on the NACA 66(215)-014 airfoil and because of the unknown tunnel correction, the measured values of drag cannot be considered absolute and are not presented in the present report. The incremental values, however, should be relatively independent of tunnel effect, and, therefore, increments of profile drag caused by deflection of the true-contour, straight-contour, and beveled-trailing-edge flaps are shown in figures 12, 13, and 14, respectively. These increments were determined by deducting the drag coefficient of the airfoil with the flap neutral from the drag coefficient with the flap deflected, with all other factors remaining constant.

For all three flap contours at $\alpha_o = 0^\circ$ and at positive flap deflections above 12°,, the increments of drag coefficient were larger with the gap unsealed than with the gap sealed.

Comparison of figures 12 to 14 indicates that deflecting the true-contour flap generally caused the largest increment of drag; whereas deflecting the beveled-trailing-edge flap caused the least increment. When the data of figures 12 to 14 were compared on an equal lift-increment basis rather than on an equal flap-deflection basis, the true-contour flap still produced larger drag increments than the other flaps over a range of about 0.4 in Δc_l, but the difference in the increments was much less than shown in the figures.

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CONCLUSIONS

Tests have been made of the NACA 66(215)-014 airfoil equipped with true-contour, straight-contour, and beveled-trailing-edge flaps having chords equal to 30 percent of the airfoil chord. The effects that increasing the trailing-edge angle had in decreasing the lift over the airfoil trailing edge were not significantly different from the effects previously noted on conventional airfoils and are contained in the following conclusions:

1. The slope of the airfoil lift curve was largest with the sealed true-contour flap and decreased as the gap at the flap nose was opened, as the trailing-edge angle was increased, and as roughness was added to the airfoil leading edge.

2. The slope of the lift curve with controls free (zero flap hinge moment) generally increased as the trailing-edge angle increased and as roughness was added to the airfoil leading edge. The effect of the gap at the hinge line varied with trailing-edge angle and with the addition of roughness to the airfoil leading edge.

3. The effectiveness of the flap in producing lift was greatest with the true-contour flap and generally decreased as the gap at the flap nose was opened, as the trailing-edge angle was increased, and as roughness was added to the airfoil leading edge.

4. The slope of the curves of hinge moment plotted against angle of attack at a flap deflection of 0° and small angles of attack was approximately zero for the straight-contour flap, negative for the true-contour flap, and positive for the beveled-trailing-edge flap. The negative slopes of the curves of hinge moment plotted against flap deflection for all three flap contours decreased as the trailing-edge angle increased, as roughness was added to the leading edge of the airfoil, and, for the straight-contour and beveled-trailing-edge flaps, as the gap at the flap nose was unsealed.

5. When the lift was varied by changing the angle of attack at zero flap deflection, the aerodynamic center of the smooth airfoil with a sealed gap moved forward as

the trailing-edge angle was increased. Unsealing the gap had little effect on the aerodynamic center; whereas the addition of leading-edge roughness moved the aerodynamic center forward 1 or 2 percent of the airfoil chord. At constant angle of attack the aerodynamic center of lift caused by flap deflection also tended to move forward as the trailing-edge angle was increased. Unsealing the gap or adding roughness at the airfoil leading edge tended to move the aerodynamic center rearward for the true-contour flap and forward for the beveled-trailing-edge flap.

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REFERENCES

1. Gillis, Clarence L., and Lockwood, Vernard E.: Wind-Tunnel Investigation of Control-Surface Characteristics. XIII - Various Flap Overhangs Used with a 30-Percent-Chord Flap on an NACA 66-009 Airfoil. NACA ACR No. 3G20, July 1943.

2. Sears, Richard I., and Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. II - A Large Aerodynamic Balance of Various Nose Shapes with a 30-Percent-Chord Flap on an NACA 0009 Airfoil. NACA A.R.R., Aug. 1941.

3. Sears, Richard I., and Gillis, Clarence L.: Wind-Tunnel Investigation of Control-Surface Characteristics. VIII - A Large Aerodynamic Balance of Two Nose Shapes Used with a 30-Percent-Chord Flap on an NACA 0015 Airfoil. NACA A.R.R., July 1942.

4. Jones, Robert T., and Ames, Milton B., Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. V - The Use of a Beveled Trailing Edge to Reduce the Hinge Moment of a Control Surface. NACA A.R.R., March 1942.

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5. Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surfaces Characteristics. X - A 30-Percent-Chord Plain Flap with Straight Contour on the NACA 0015 Airfoil. NACA A.R.R., Sept. 1942.

6. Purser, Paul E., and Gillis, Clarence L.: Preliminary Correlation of the Effects of Beveled Trailing Edges on the Hinge-Moment Characteristics of Control Surfaces. NACA CB No. 3E14; May 1943.

7. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. Rep. No. 387, NACA, 1931.

8. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Supplement (loose-leaf) to NACA Advance Confidential Report, Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence. NACA, March 1942.

9. Sears, Richard I.: Wind-Tunnel Data on the Aerodynamic Characteristics of Airplane Control Surfaces. NACA ACR No. 3L08; Dec. 1943.

10. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. Rep. No. 721, NACA, 1941.

TABLE I

ORDINATES FOR NACA 66(215)-014 AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
0	0	0
.5	1.036	-1.036
.75	1.240	-1.240
1.25	1.535	-1.535
2.5	2.080	-2.080
5.0	2.880	-2.880
7.5	3.506	-3.506
10	4.048	-4.048
15	4.904	-4.904
20	5.566	-5.566
25	6.081	-6.081
30	6.470	-6.470
35	6.748	-6.748
40	6.920	-6.920
45	6.995	-6.995
50	6.962	-6.962
55	6.807	-6.807
60	6.497	-6.497
65	5.978	-5.978
70	5.224	-5.224
75	4.342	-4.342
80	3.375	-3.375
85	2.375	-2.375
90	1.389	-1.389
95	.523	-.523
100	.095	-.095
L.E. radius: 1.206		

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TABLE II

PARAMETER VALUES OF FLAPS OF 0.30c TESTED ON THE NACA 66(215)-014 AIRFOIL IN THE NACA 4- BY 6-FOOT VERTICAL TUNNEL

Parameters	Leading-edge surface	True-contour flap; $\phi = 18^\circ$		Straight-contour flap; $\phi = 19.3^\circ$		Beveled-trailing-edge flap; $\phi = 30^\circ$	
		Gap, sealed	Gap, 0.002c	Gap, sealed	Gap, 0.002c	Gap, sealed	Gap, 0.002c
$\left(\frac{\partial \alpha_o}{\partial \delta_f}\right)_{c_l}$	Smooth	-0.58	-0.59	-0.58	-0.53	-0.56	-0.46
	Rough	-.56	-.53	-.55	-.46	-.48	-.42
$\left(\frac{\partial c_l}{\partial \alpha_o}\right)_{\delta_f}$	Smooth	.098	.094	.090	.085	.084	.079
	Rough	.092	.088	.084	.081	.080	.077
$\left(\frac{\partial c_l}{\partial \alpha_o}\right)_{ch_f=0}$	Smooth	.064	.061	.087	.085	.189	.282
	Rough	.059	.062	.091	.091	.358	Divergent
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_f}$	Smooth	.005	.003	.028	.032	.045	.058
	Rough	.013	.011	.038	.041	.062	.062
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\alpha_o}$	Smooth	-.160	-.183	-.172	-.184	-.159	-.150
	Rough	-.189	-.213	-.174	-.180	-.132	-.125
$\left(\frac{\partial ch_f}{\partial \alpha_o}\right)_{\delta_f}$	Smooth	-.0081	-.0088	-.0005	0	.0049	.0056
	Rough	-.0079	-.0077	.0008	.0010	.0057	.0058
$\left(\frac{\partial ch_f}{\partial \delta_f}\right)_{\alpha_o}$	Smooth	-.0134	-.0146	-.0076	-.0059	-.0022	-.0010
	Rough	-.0122	-.0140	-.0052	-.0036	-.0008	.0010

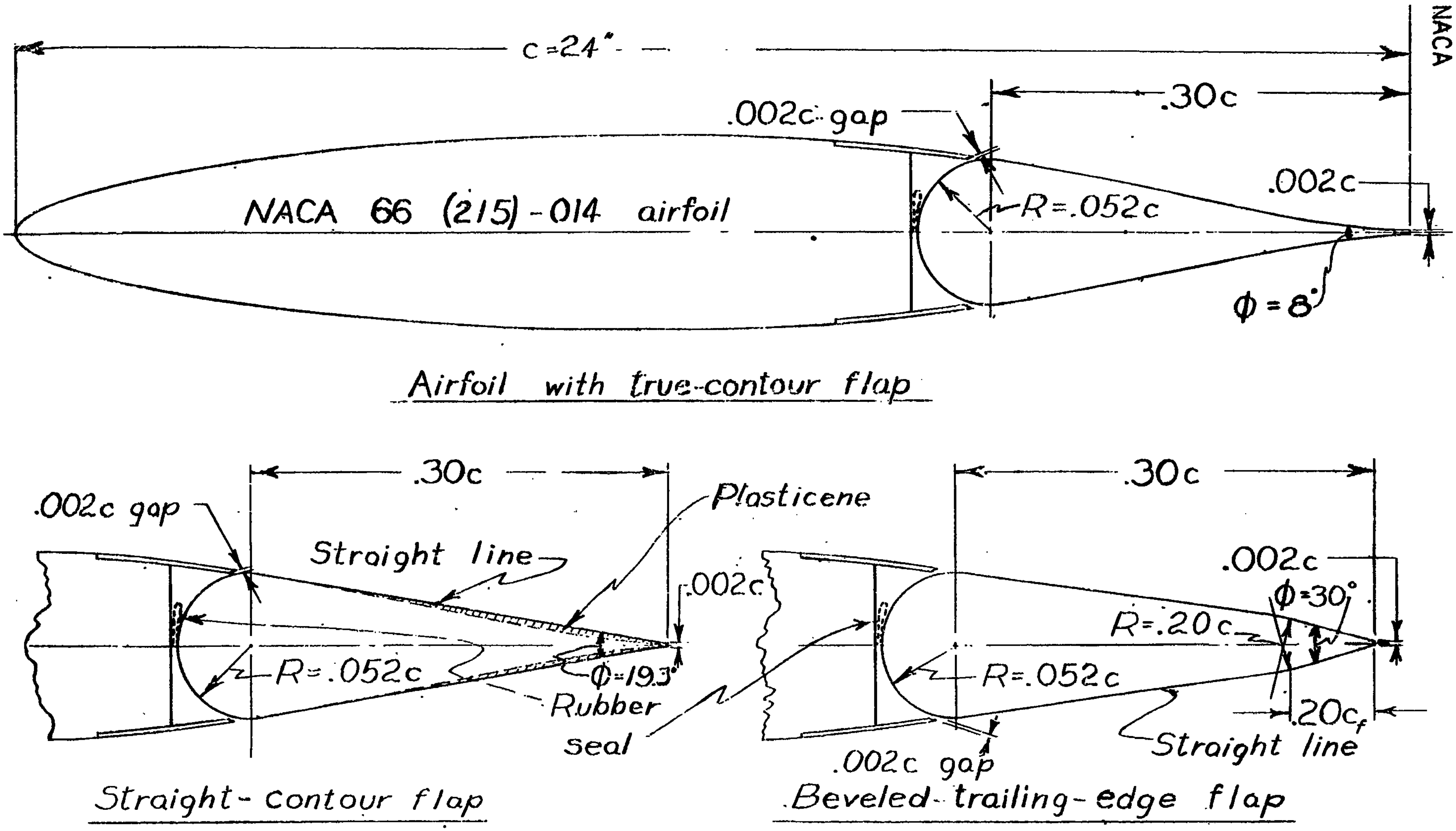

Figure 1.- Details of flaps tested on NACA 66 (215)-014 airfoil.

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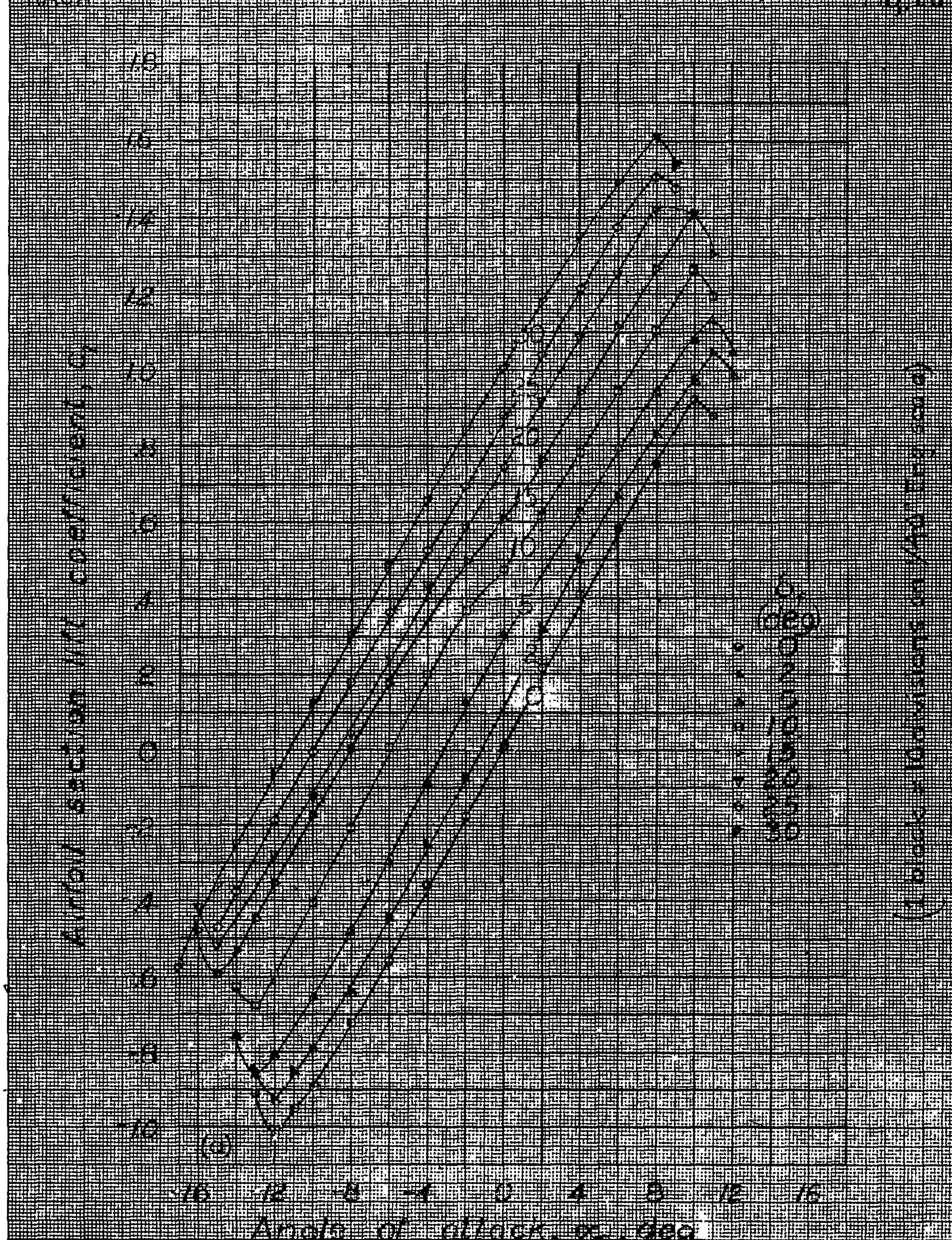

Figure 2.- Aerodynamic section characteristics of an NACA 65 (215)-014 airfoil having a 0.30c true-contour flap. Gap, 0.002c.

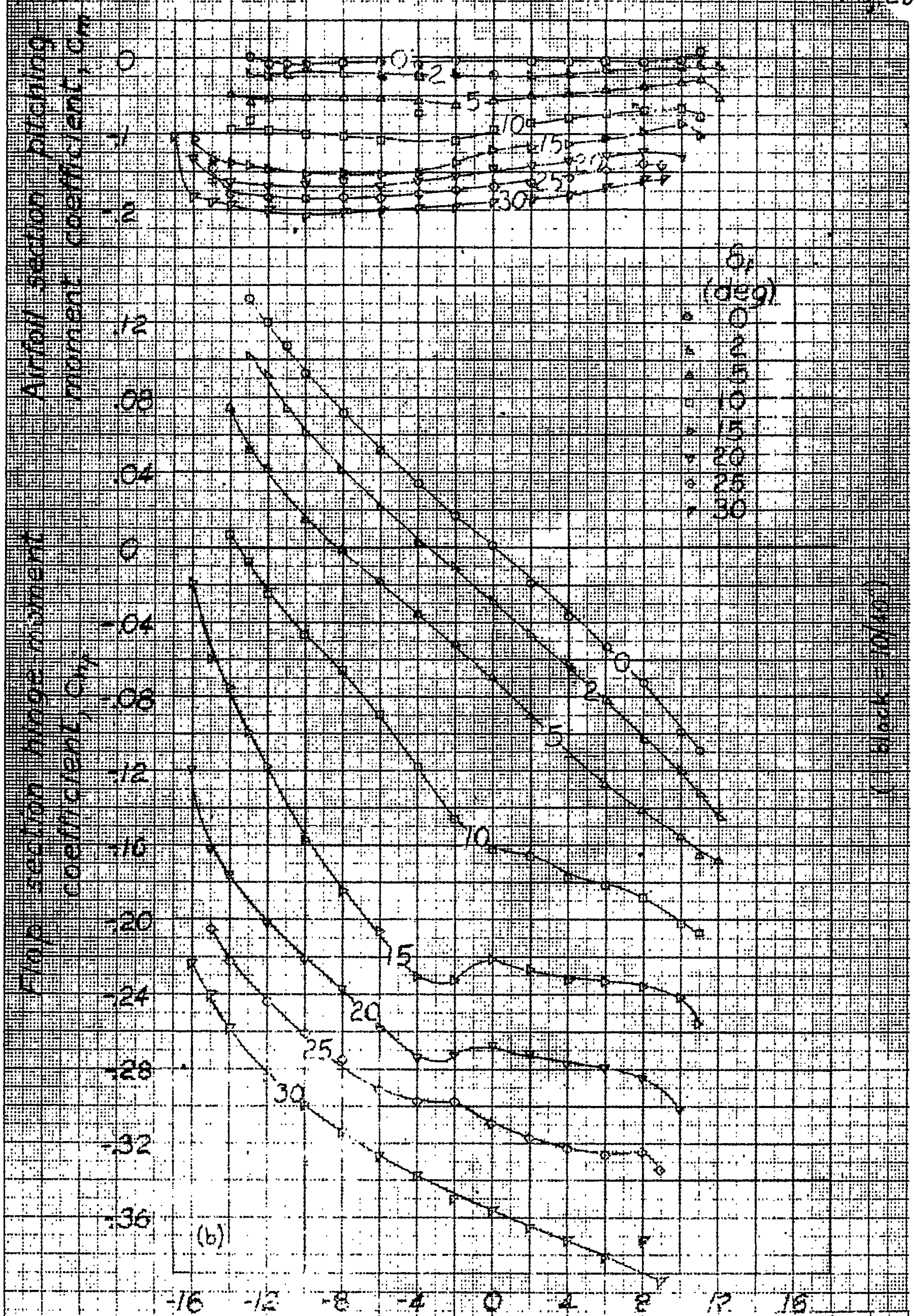

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Figure 2.- Concluded.

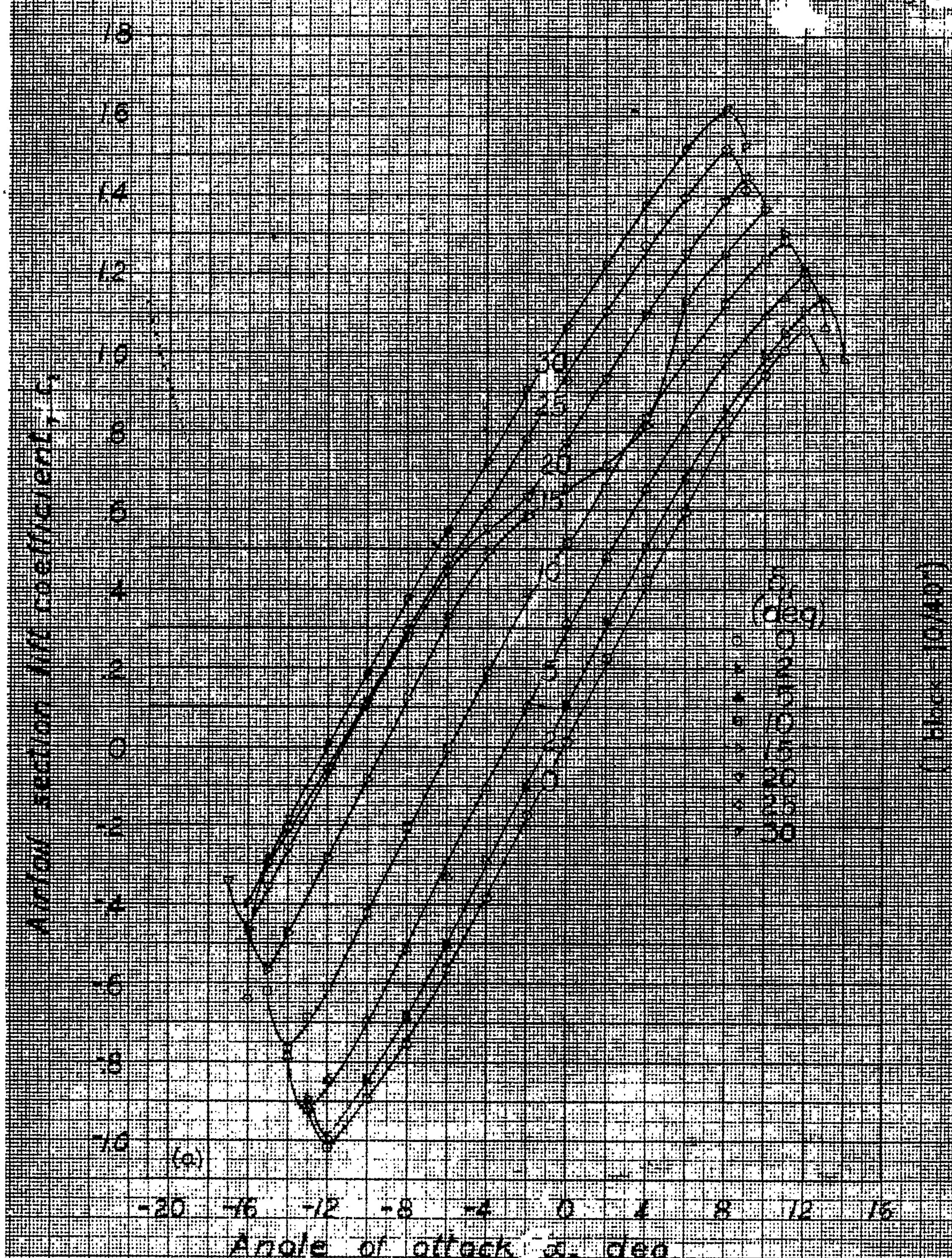

Figure 3.-Aerodynamic section characteristics of an NACA 66(215)-014 airfoil having a 0.30c true-contour flap. Gap sealed

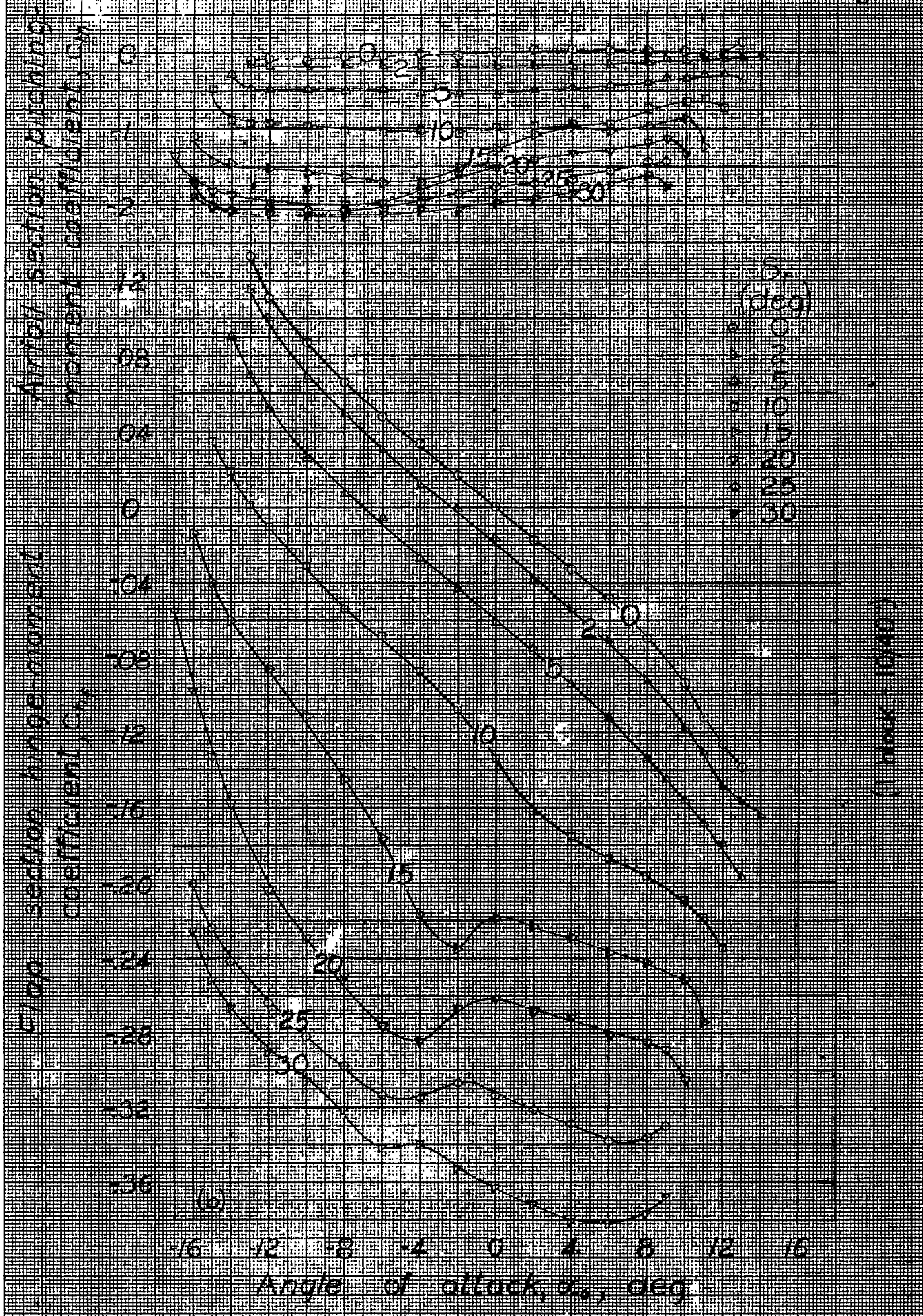

Figure 3.- Concluded.

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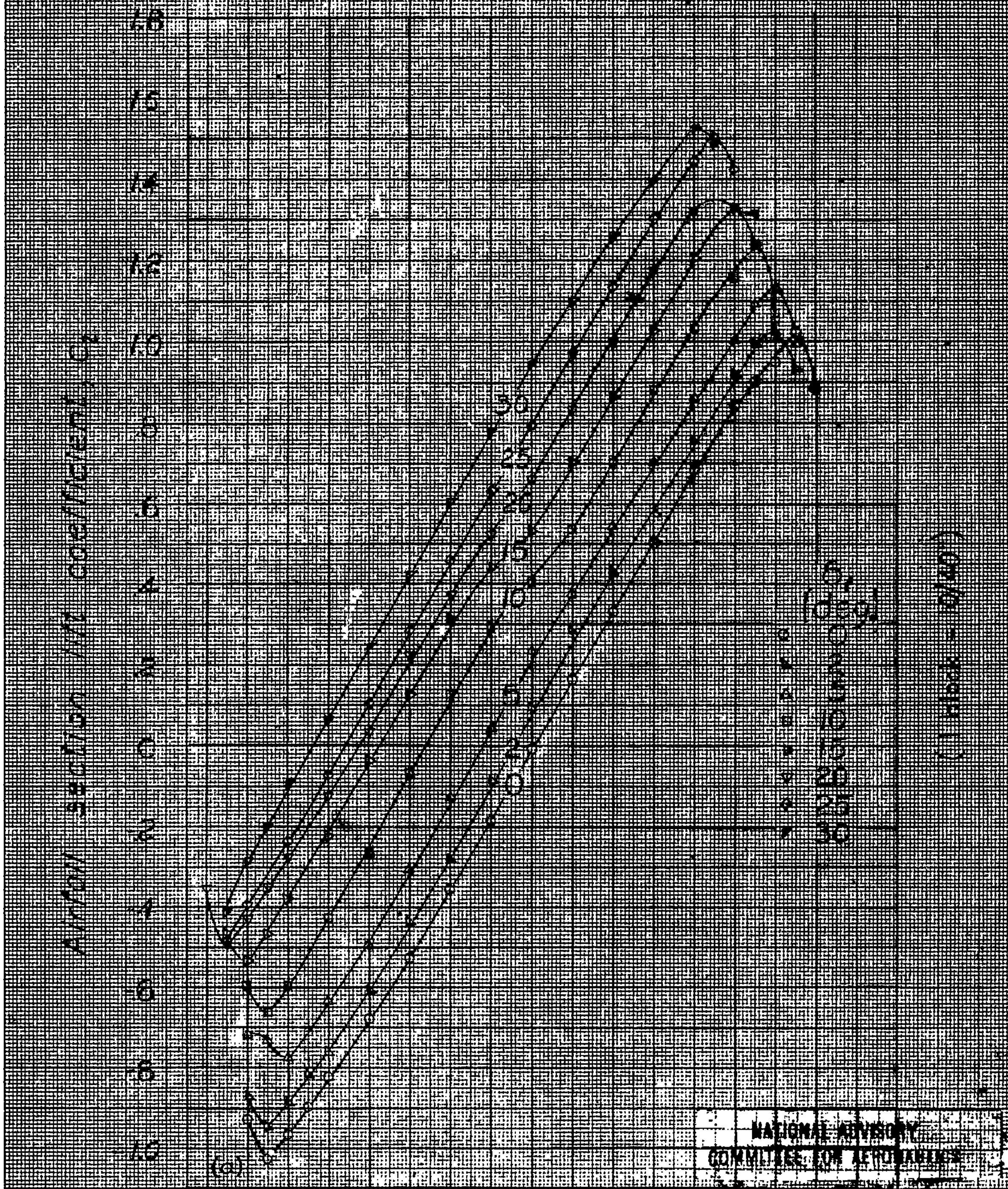

Figure 4- Aerodynamic section characteristics of an NACA 66 (215)-014 airfoil having a 0.30c straight-contour flap. Gap, 0.002c.

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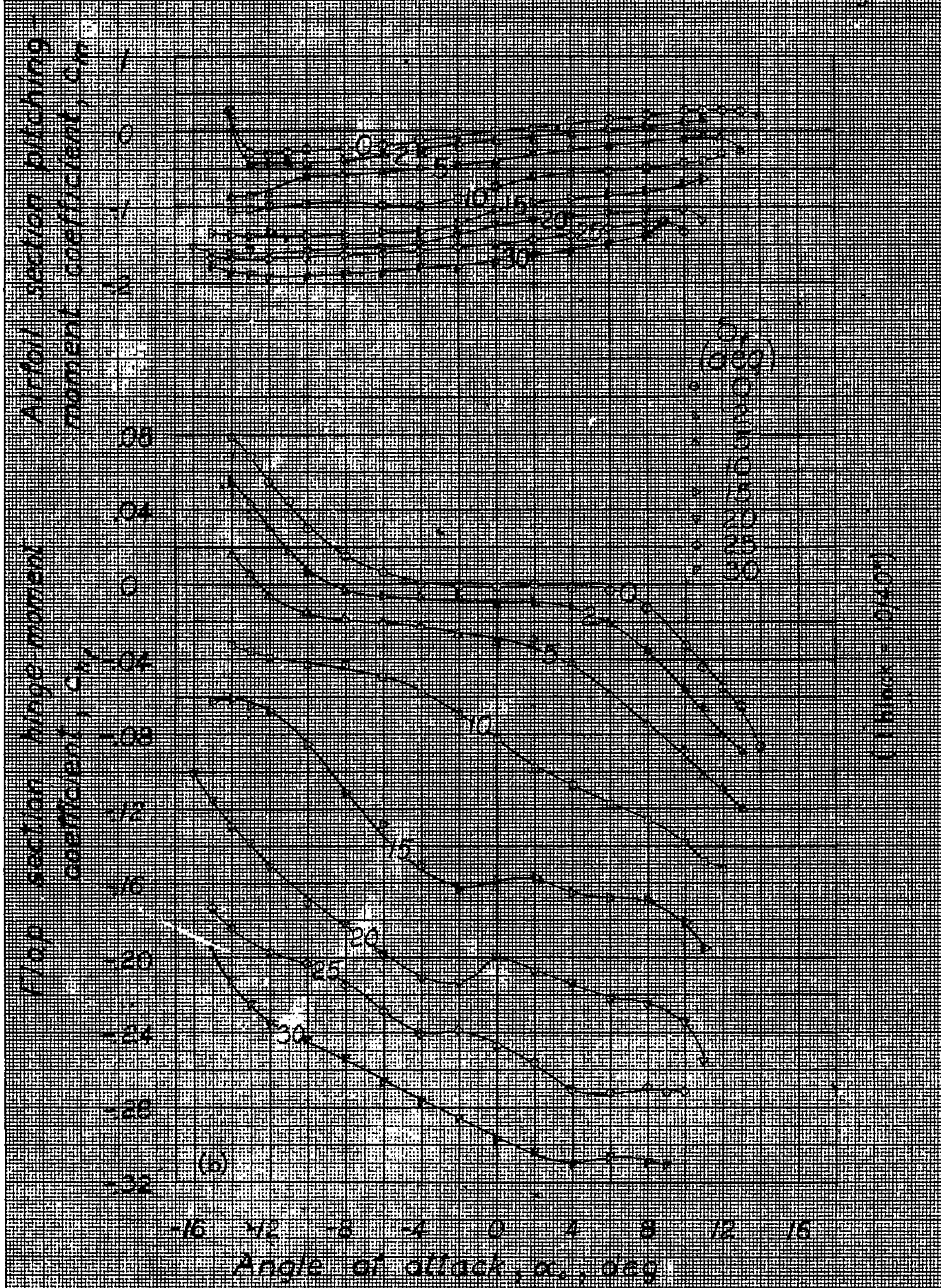

Figure 4.- Concluded.

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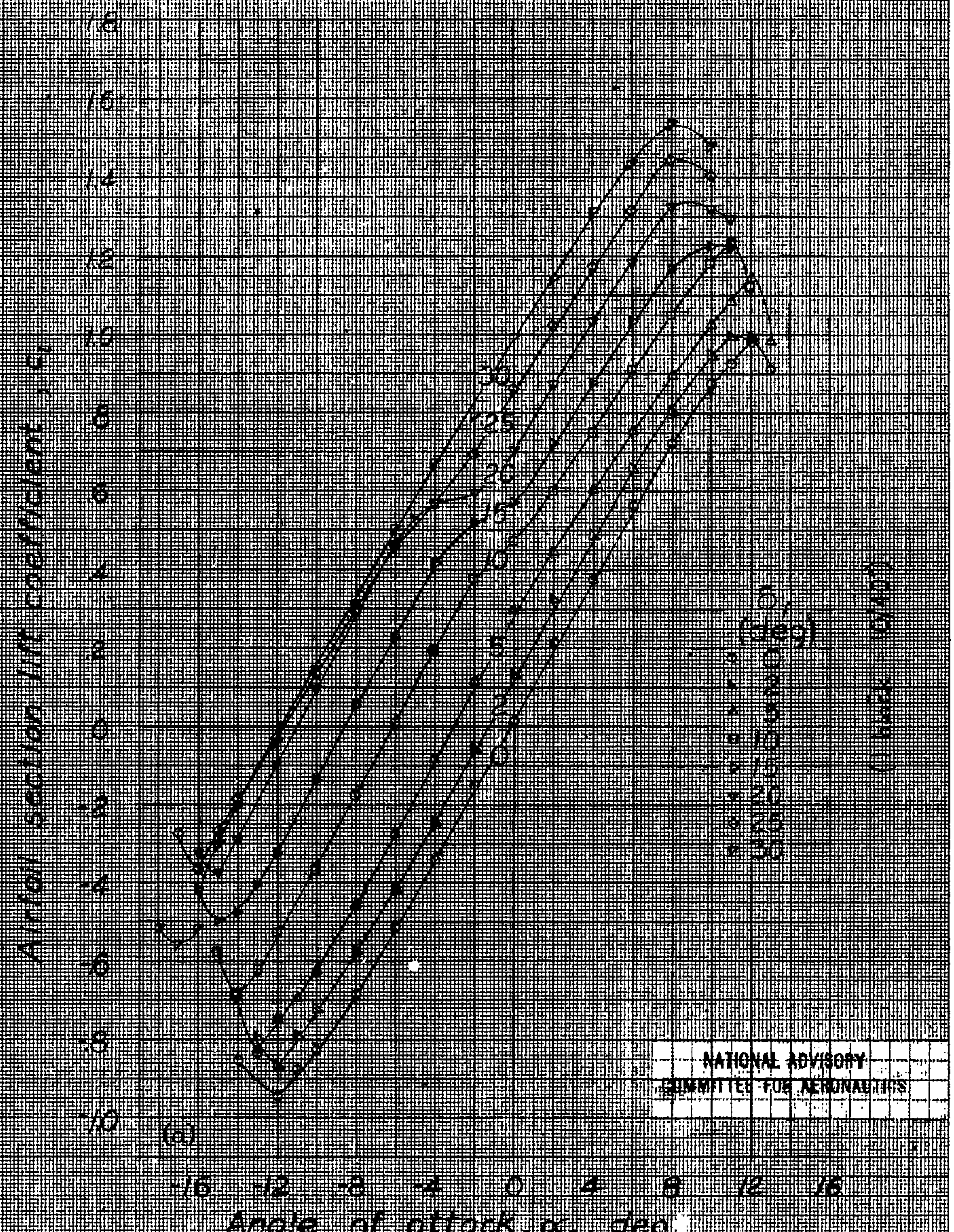

Figure 5.- Aerodynamic section characteristics of an NACA 66(215)014 airfoil having a 0.30c straight-contour flap. Gap sealed.

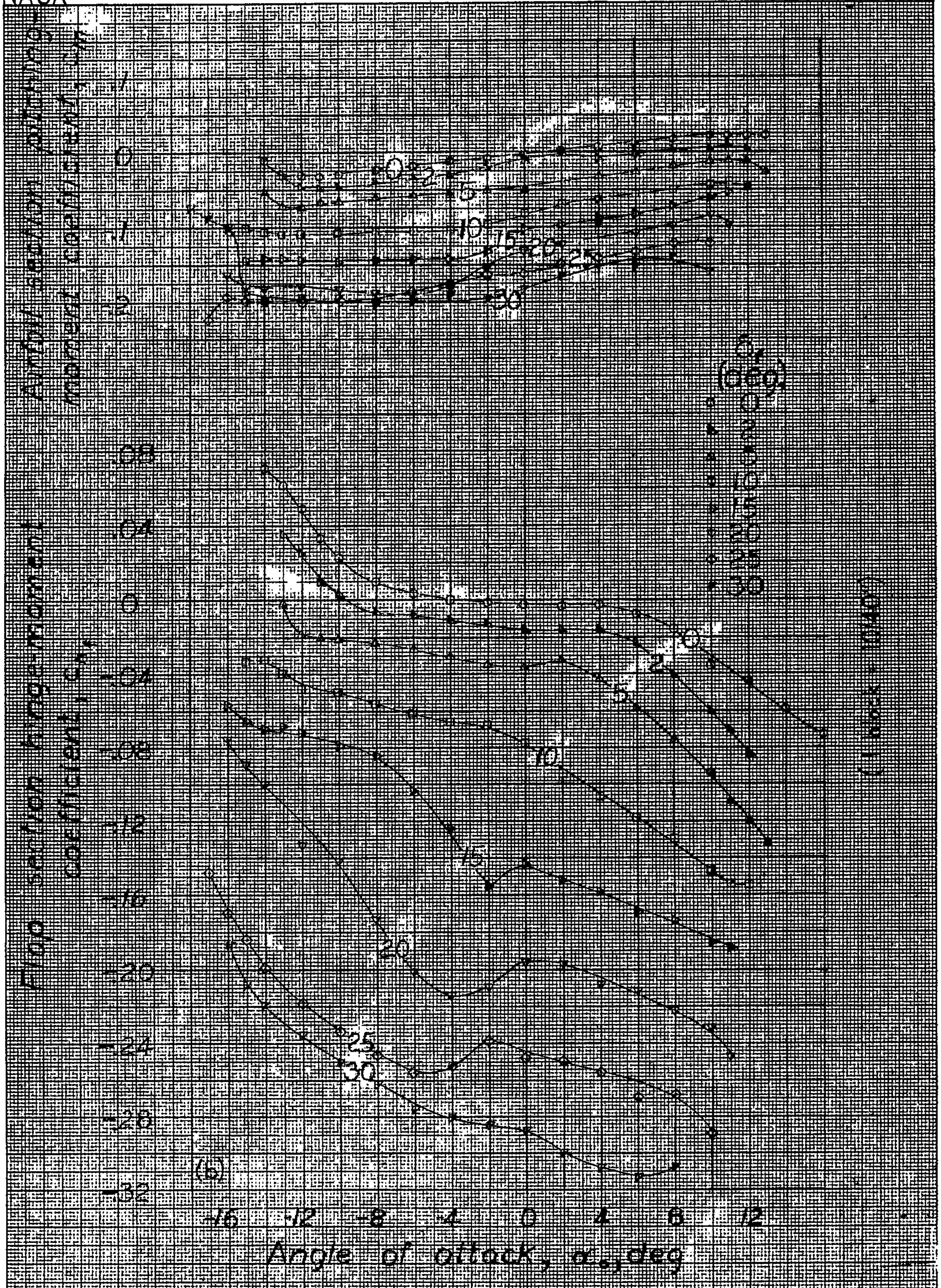

Figure 5.- Concluded.

(b)

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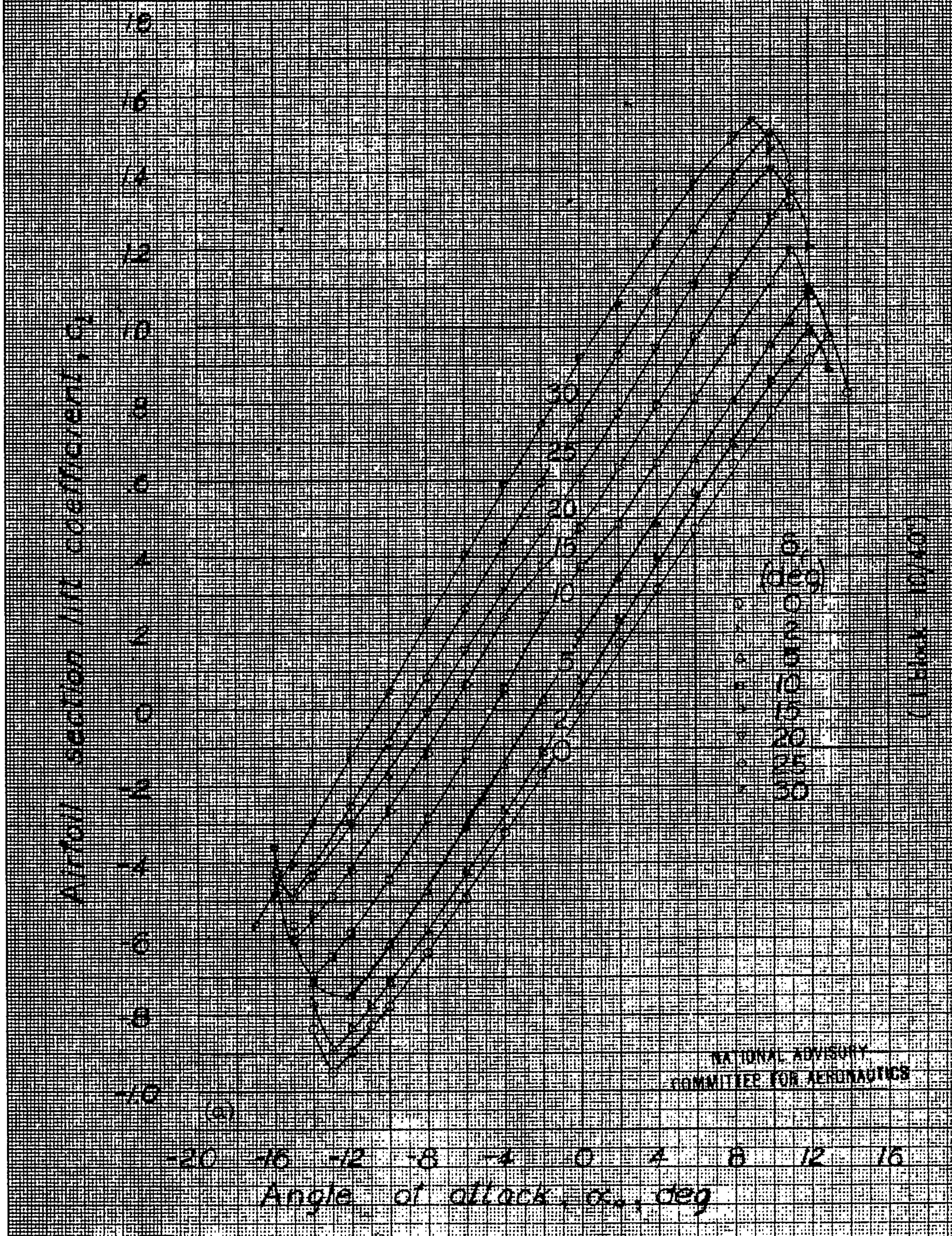

Figure 6.- Aerodynamic section characteristics of an NACA 66 (215)-014 airfoil having a 0.30c beveled-trailing-edge flap. Gap, 0.002c.

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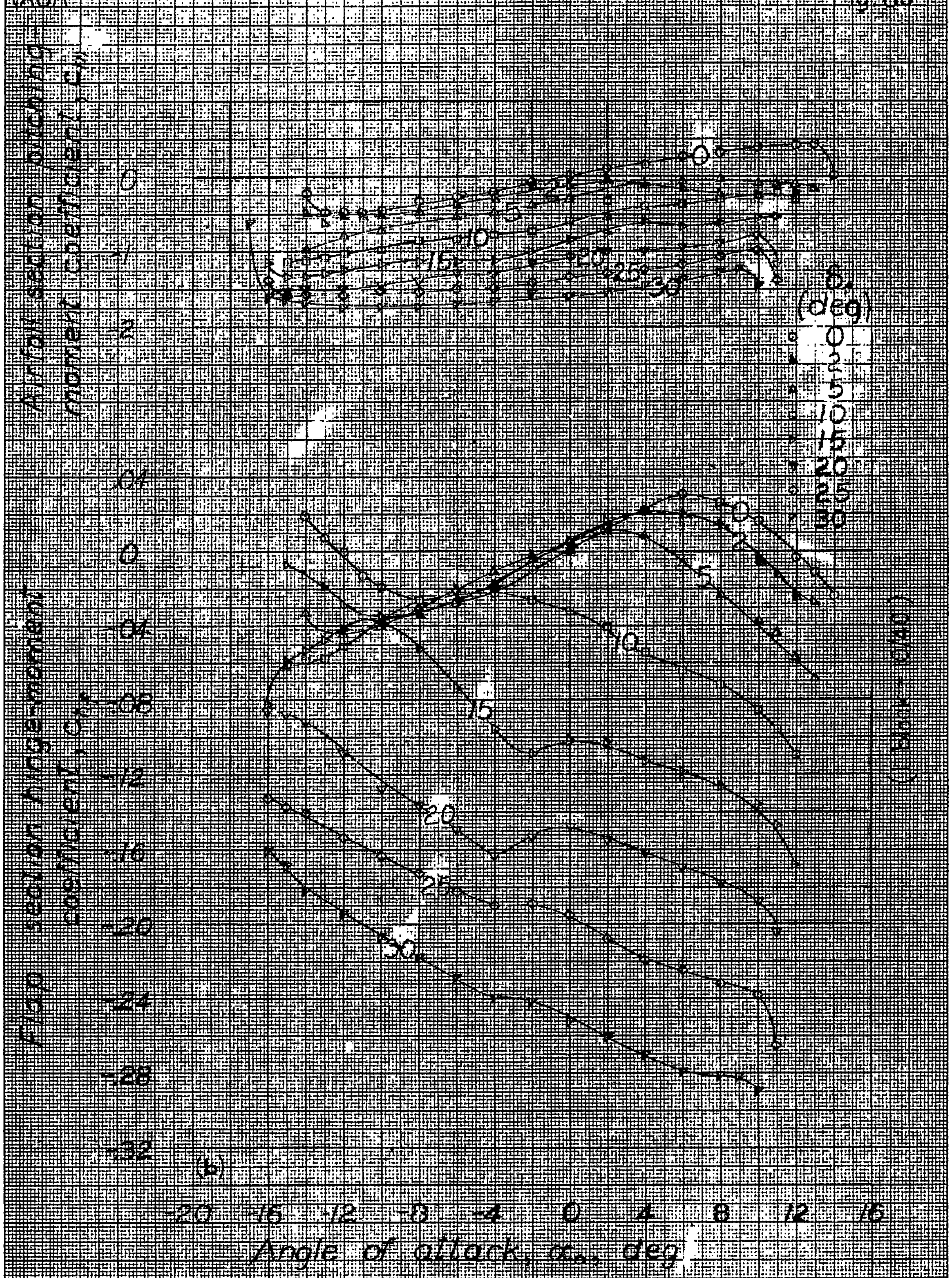

Figure 6-Concluded.

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WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE
CHARACTERISTICS. XV - VARIOUS CONTOUR MODIFICATIONS
OF A 0.30-AIRFOIL-CHORD PLAIN FLAP ON AN NACA
66(215)-014 AIRFOIL

By Paul E. Purser and John M. Riebe

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE CONFIDENTIAL REPORT

WIND-TUNNEL INVESTIGATION OF CONTROL-SURFACE CHARACTERISTICS. XX - VARIOUS CONTOUR MODIFICATIONS OF A 0.30-AIRFOIL-CHORD PLAIN FLAP ON AN NACA 66(215)-014 AIRFOIL

By Paul E. Purser and John M. Riebe

SUMMARY

Force-test measurements in two-dimensional flow have been made in the NACA 4- by 6-foot vertical tunnel to determine the aerodynamic characteristics of an NACA 66(215)-014 airfoil equipped with true-contour, straight-contour, and beveled-trailing-edge flaps having chords 30 percent of the airfoil chord. The results are presented in the form of aerodynamic section characteristics for several flap deflections and for a sealed and unsealed gap at the flap nose.

The slope of the lift curve, the effectiveness of the flap, and the negative slopes of the hinge-moment curves generally decreased as the trailing-edge angle was increased, as the gap at the flap nose was opened, and as roughness was added to the leading edge of the airfoil.

The aerodynamic center of lift caused by changing angle of attack moved forward as the trailing-edge angle was increased and as roughness was added to the airfoil leading edge. The aerodynamic center of lift caused by changing flap deflection tended to move forward when the trailing-edge angle was increased and, when roughness was added to the airfoil leading edge, tended to move rearward for the true-contour flap, to remain unchanged for the straight-contour flap, and to move forward for the beveled-trailing-edge flap.

The effects of beveled trailing edges on the characteristics of a plain flap on a low-drag airfoil were not

significantly different from the effects previously noted for similar modifications on conventional airfoils.

INTRODUCTION

An extensive two-dimensional-flow investigation of the aerodynamic section characteristics of airfoils with flaps has been undertaken by the NACA to determine the types of flap arrangement best suited for use as control surfaces and to supply experimental data for design purposes. The investigation has included modifications of flap-nose shape, balance length, and gap size on a 9-percent thick low-drag airfoil and on 9- and 15-percent-thick conventional airfoils. Other modifications have included the use of a straight-contour flap and a beveled-trailing-edge flap. The results of some of these investigations were reported in references 1 to 5. Reference 6 has used the trailing-edge angle of the beveled-trailing-edge flap as a basis for correlation.

High-speed airplanes require the use of airfoil sections with low peak pressures, such as low-drag sections, for tail surfaces to alleviate the danger of shock stall. In order to extend airfoil profile alterations to low-drag airfoil contours, tests have been made of the NACA 66(215)-014 airfoil equipped with true-contour, flat-contour, and beveled-trailing-edge flaps. Throughout the present paper, the flap having the same contour as the trailing edge of the basic airfoil will be referred to as the true-contour flap, the flap having a contour formed by straight lines drawn from the flap nose arc to the trailing edge as the straight-contour flap, and the flap formed by thickening and beveling the trailing-edge portion of a straight-contour flap as the beveled-trailing-edge flap.

APPARATUS AND MODEL

The tests were made in the NACA 4- by 6-foot vertical tunnel described in reference 7. The test section of this tunnel has been converted from the original open, circular, 5-foot diameter jet to a closed, rectangular, 4- by 6-foot throat for force tests of models in two-dimensional flow. A three-component balance system has been installed in the tunnel to measure lift, drag, and pitching moments. The hinge moments of the flap were measured from a special torque-rod balance built into the model.

The 2-foot-chord by 4-foot-span model (fig. 1) was built of laminated mahogany to the NACA 66(215)-014 profile. (See table I.) The airfoil was equipped with a true-contour flap and a beveled-trailing-edge flap with chords 30 percent of the airfoil chord (0.30c). The cusp of the true-contour flap was filled in with plasticine to form the straight-contour flap used in part of the tests. The nose radius of each flap was approximately one-half the airfoil thickness at the flap hinge axis, and the flap gap was 0.002c. For the sealed-gap tests, a rubber sheet was connected between the nose of the flap and the airfoil.

The model, when mounted in the tunnel, completely spanned the test section and was attached to the balance frame by torque tubes that extended through the sides of the tunnel. The angle of attack was set from outside the tunnel by rotating the torque tubes with an electric drive.

TESTS

The tests were made at dynamic pressures of 11.25 and 15.00 pounds per square foot, which correspond, respectively, to airspeeds of about 66 and 76 miles per hour at standard sea-level conditions. The effective Reynolds numbers of the tests were approximately 2,400,000 and 2,760,000. The effective Reynolds number is the product of the test Reynolds number and the turbulence factor, which is 1.93 for the 4- by 6-foot vertical tunnel.

The three flap contours tested were set at flap deflections from 0° to 30° in increments to 5°, including an additional deflection of 2°, with the gap both sealed and unsealed. For each flap setting, the values of lift, drag, pitching moment, and flap hinge moment were read throughout the angle-of-attack range from negative stall to positive stall. All readings were taken at increments of angle of attack of 2°, except near the stall where the increment was reduced to 1°.

Force tests were also made at an angle of attack of 0°, at flap deflections from 0° to 30° in increments of 5° (including an additional deflection of 2°) in order to provide a check for the tests previously mentioned and to obtain data for measuring some of the parameters without cross-plotting.

In order to determine the effect of a fixed transition point near the leading edge on the aerodynamic characteristics, force tests were also made with surface roughness extending back approximately 2.7 inches (0.11c) from the airfoil leading edge. The roughness consisted of carborundum particles of the size and distribution referred to as standard roughness in reference 8.

The accuracy of the data is indicated by the deviation from zero of the lift and moment coefficients at an angle of attack of 0° with the flap neutral. The maximum error in effective angle of attack at zero lift appeared to be about $\pm 0.2^\circ$. Flap deflections were set to within $\pm 0.2^\circ$. Tunnel corrections, experimentally determined in the 4- by 6-foot vertical tunnel, were applied only to lift. The hinge moments are probably slightly higher than would be obtained in free air and, consequently, the values presented are considered conservative. (See reference 9.) The increments of drag should be reasonably independent of tunnel effect, although the absolute values are subject to unknown tunnel and turbulence corrections.

SYMBOLS

The coefficients and symbols used in this paper are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient about quarter-chord point of airfoil (m/qc^2)

c_{h_f} flap section hinge-moment coefficient $(h_f/qc_f{}^2)$

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point of airfoil

h_f flap section hinge moment

c chord of basic airfoil with flap neutral

c_f flap chord

q dynamic pressure

and

α_o angle of attack for airfoil of infinite aspect ratio, degrees

δ_f flap deflection with respect to airfoil, degrees

ϕ trailing edge angle - included between sides which form trailing edge of flap, degrees.

R_e effective Reynolds number

PRESENTATION OF RESULTS

The aerodynamic section characteristics of the NACA 66(215)-014 airfoil for a gap of 0.002c and for the gap sealed are presented in figures 2 and 3, respectively, for the 0.30c true-contour flap, in figures 4 and 5, respectively, for the 0.30c straight-contour flap, and in figures 6 and 7, respectively, for the 0.30c beveled-trailing-edge flap.

A comparison of the aerodynamic section characteristics at zero flap deflection with smooth and roughened leading edge for the true-contour, straight-contour, and beveled-trailing-edge flaps is shown in figure 8 with a gap of 0.002c and in figure 9 with the gap sealed. The variation of the aerodynamic section characteristics with flap deflection for the true contour, straight-contour, and beveled-trailing-edge flaps with a smooth and roughened leading edge at zero angle of attack is shown in figures 10 and 11 with a gap of 0.002c and with the gap sealed, respectively.

Increments of section profile-drag coefficient caused by deflecting the flaps are given in figure 12 for the true-contour flap, in figure 13 for the straight-contour flap, and in figure 14 for the beveled-trailing-edge flap. Figure 15 shows the effect of Reynolds number on the airfoil with the true-contour flap at zero deflection with the gap sealed.

The flap hinge-moment parameters $\left(\partial c_{h_f}/\partial \alpha_0\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_0}$ are shown in figure 16 as functions of the trailing-edge angle for a gap of 0.002c and for the gap sealed with a smooth and roughened leading edge. The various parameters for the true-contour, straight-contour, and beveled-trailing-edge flaps, which are presented for comparison in table II, are the values of slopes measured at an angle of attack and a flap deflection of 0°.

DISCUSSION OF RESULTS

Lift

General shape of lift curves.- The lift curves of the straight-contour or beveled-trailing-edge flaps for various flap deflections and for the gap open (figs. 4 and 6) or for the gap closed (figs. 5 and 7) have the same general shape as the lift curves of the true-contour flap for the gap open (fig. 2) or for the gap closed (fig. 3). The gap-open and gap-sealed conditions have different flap deflection ranges where the lift curves approach the linear conditions. For the gap-open conditions, some nonlinearily occurs for the 10° and 15° flap deflections; whereas, for the gap-sealed condition, this nonlinearity is most noticeable for the 15° and 20° flap deflections. As the trailing-edge angle increases, the range of flap deflections over which this nonlinearity occurs tends to become larger when the gap is sealed and to remain the same when the gap is open.

The angle of attack at which the airfoil stalled tended to increase slightly as the trailing-edge angle increased with the gap open but was approximately the same with the gap sealed. A comparison of figures 2 and 3 with the data of reference 1 indicates that the lift curves for various deflections of the true-contour flap for both the sealed and unsealed gap on the NACA 66(215)-014 airfoil are more linear and indicate stall at greater angles of attack than those of the NACA 66-009 airfoil.

Slope of lift curves.- The slope of the lift curve $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ for the true-contour flap was larger than that for the straight-contour or beveled-trailing-edge flap with the sealed or unsealed gap. (See table II.) The decrease in $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ for the three flap contours that occurred with increasing trailing-edge angle may be attributed to the increased thickness of the after portion of the airfoil, which caused an increased deviation in flow from the theoretical flow for thin airfoils. A decrease in $\left(\partial c_l/\partial \alpha_0\right)_{\delta_f}$ also occurred for the three flap contours when the gap was unsealed. This trend agrees qualitatively with the results for the NACA 0009, 0015, and 66-009 airfoils (references 1 to 5).

Effectiveness of flap.- The effectiveness of the flaps $\left(\partial \alpha_0/\partial \delta_f\right)_{c_l}$ was greatest for the true-contour flap and was approximately the same with the gap both sealed and unsealed. As the trailing-edge angle increased, the effectiveness decreased; and unsealing the gap further reduced the flap effectiveness (table II).

With the gap unsealed, all flaps tested were effective in producing positive increments of lift at all positive flap deflections within the unstalled range of angle of attack. The flap effectiveness at zero angle of attack and small flap deflections was greater with the gap sealed than with the gap unsealed, but the increments of lift for the high flap deflections with the gap sealed were very small or zero in part of the negative angle-of-attack range. Although a drop in effectiveness occurred at high flap deflections at negative angles of attack, the drop in effectiveness with flap deflection at the positive angle of attack was not so pronounced for the NACA 66(215)-014 airfoil as for the NACA 66-009 airfoil (reference 1) and 0015 airfoil (reference 5).

Slope of lift curves with controls free.- The parameter $(\partial c_l/\partial \alpha_0)_{c_{h_f}} = 0$ (table II) is a measure of control-free stability. The slope of the control-free lift curve was less than that of the control-fixed lift curve for the true-contour flap with the gap either sealed or unsealed. For the straight-contour flap the slope of the lift curve with control free was smaller than with control fixed for the sealed gap; whereas no change occurred for the open gap. The slope of the control-free lift curve was larger than that of the control-fixed lift curve for the beveled-trailing-edge flap, being greater when the gap was unsealed than when sealed. Comparison of the data for the three flap contours shows an increase in $(\partial c_l/\partial \alpha_0)_{c_{h_f}} = 0$ with trailing-edge angle.

It should be noted that these statements are based on slope values measured over a small angular range and their use is therefore limited to stability calculations and other applications which are concerned only with small changes in angle of attack and deflection.

Effect of leading-edge roughness.- The effect of roughness on the airfoil leading edge was to decrease the slope of the airfoil lift curves and the effectiveness of the true-contour, straight-contour, and beveled-trailing-edge flaps for the gap both sealed and unsealed. (See table II.) The presence of roughness on the airfoil leading edge did not change the tendency of the open gap and the increased trailing-edge angle to reduce the slope of the airfoil lift curve and the flap effectiveness.

With controls free the slopes of the lift curves were larger with a roughened leading edge than with a smooth leading edge in all cases except that of the true-contour flap with gap sealed and the beveled-trailing-edge flap with gap unsealed. For the beveled-trailing-edge flap with gap unsealed the presence of roughness resulted in an unstable condition because both $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ and $(\partial c_{h_f}/\partial \delta_f)_{\alpha_o}$ were positive.

The lift coefficient increased relatively linearly with the flap deflections above 10° with either smooth or roughened leading edge when the gap was sealed or unsealed (figs. 10 and 11). The general effect of roughness, however, was to reduce the lift coefficient at a given flap deflection and to reduce the maximum lift coefficient.

Effect of Reynolds number.- An increase in effective Reynolds number from approximately 2,400,000 to 2,760,000 increased the maximum lift coefficient from 1.06 to 1.13 at positive angles of attack and from -1.01 to -1.20 at negative angles of attack for the NACA 66(215)-014 airfoil with a true-contour flap at $\delta_f = 0^\circ$ with the gap sealed. (See fig. 15.) Increasing the effective Reynolds number caused a slight increase in the slope of the lift curve. The differences in the angles of attack for zero lift for the two tests is within the limits noted previously under "Tests" and is probably the result of errors in setting the angle of attack or flap deflection.

Hinge Moment of Flap

General shape of hinge-moment curves.- The curves of flap section hinge moment plotted against angle of attack (figs. 2 to 7) were not unusual except for the breaks that occurred at the intermediate and high flap deflections. These breaks, generally larger with the gap sealed than with the gap unsealed, were probably the result of flow separation over the flap.

Slope of hinge-moment curves.- The hinge-moment parameters for the three flap contours with the gap sealed and unsealed are given in table II. Because of the nonlinearity of the hinge-moment curves over most of the angle-of-attack range, the parameter $(\partial c_{h_f}/\partial \alpha_o)_{\delta_f}$ was measured at $\delta_f = 0^\circ$ and $\alpha_o = 0^\circ$ over the linear range previously mentioned. Although this range is small, these values can be used for comparing the three flap contours and for stability computations; however, for a complete comparison the entire set of hinge-moment curves must be taken into consideration.

The measured slope $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ was zero for the straight-contour flap with the gap unsealed; however, for the gap both sealed and unsealed, $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ was negative for the true-contour flap and was positive, showing an overbalance, for the beveled-trailing-edge flap. (See figs. 8 and 9.) The value $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ was more positive for the flaps with the larger trailing-edge angles. This trend agrees qualitatively with the data of reference 4, but the actual value of the change is larger than that indicated by the curves of reference 6.

Values of the parameter $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ (figs. 10 and 11) were measured at flap deflections from 0° to 5° because of the nonlinearity of the flap section hinge-moment curves throughout the flap deflection range. An increase in trailing-edge angle produces a decrease in the negative value of $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ for the gap sealed or unsealed (table II). This trend also agrees with the data of reference 4 but the actual values are again larger than those indicated by the curves of reference 6.

Effect of leading-edge roughness.- The effect of leading edge roughness on the variation of $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ with trailing-edge angle and gap condition for the 0.30c flaps on the NACA 66(215)-014 airfoil (fig. 16) was to make both $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ more positive. The presence of leading-edge roughness did not alter the general tendency of $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ to become more positive with increases in trailing-edge angle and with unsealing the gap.

Effect of Reynolds number.- An increase in effective Reynolds number from approximately 2,400,000 to 2,760,000 slightly increased the negative value of $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$

for the true-contour flap at $\delta_f = 0^\circ$ with the gap sealed (fig. 15). The difference in the values of the hinge-moment coefficient at $\alpha_o = 0^\circ$ probably resulted from errors in setting the angle of attack and flap deflection.

Pitching Moment

The values of the parameters $(\partial c_m/\partial c_l)_{\alpha_o}$ and $(\partial c_m/\partial c_l)_{\delta_f}$, shown in table II, give the position of the aerodynamic center with respect to the quarter-chord point. When the lift was varied by changing the angle of attack at a flap deflection of 0°, the aerodynamic center of the smooth airfoil with a sealed gap was at 0.25c for the true-contour flap, 0.22c for the straight-contour flap, and 0.20c for the beveled trailing-edge flap. This trend agrees qualitatively with the results in reference 4. With roughness on the leading edge, the aerodynamic center moved slightly forward to 0.24c for the true-contour flap, to 0.21c for the straight-contour flap, and to 0.19c for the beveled-trailing-edge flap. Unsealing the gap generally had little effect on the position of the aerodynamic center. Increasing the effective Reynolds number had very little effect on the aerodynamic center of the airfoil with the sealed true-contour flap at $\delta_f = 0^\circ$ (fig. 15).

The following table gives the position of the aerodynamic center of lift due to flap deflection:

Leading edge	Aerodynamic center					
	True-contour flap		Straight-contour flap		Beveled-trailing-edge flap	
	0.002c gap	Sealed gap	0.002c gap	Sealed gap	0.002c gap	Sealed gap
Smooth	0.43c	0.41c	0.43c	0.42c	0.40c	0.41c
Rough	.46c	.44c	.43c	.42c	.38c	.38c

With roughness on the leading edge, the aerodynamic center of lift caused by flap deflection moved rearward about 0.03c for the true-contour flap, remained unchanged for the straight-contour flap, and moved 0.02c to 0.03c forward for the beveled-trailing-edge flap. The position of the aerodynamic center of lift caused by flap deflections is a function of the aspect ratio (reference 10) and moves toward the trailing edge as the aspect ratio decreases. It can be seen that, if the aerodynamic-center positions are plotted against $\left(\partial c_{h_f}/\partial \alpha_o\right)_{\delta_f}$ and $\left(\partial c_{h_f}/\partial \delta_f\right)_{\alpha_o}$ there is a general trend for the aerodynamic centers to move forward as the slopes of the hinge-moment curves become more positive.

Drag

Because the turbulence of the 4- by 6-foot vertical tunnel made it impossible for the low-drag condition to be realized on the NACA 66(215)-014 airfoil and because of the unknown tunnel correction, the measured values of drag cannot be considered absolute and are not presented in the present report. The incremental values, however, should be relatively independent of tunnel effect, and, therefore, increments of profile drag caused by deflection of the true-contour, straight-contour, and beveled-trailing-edge flaps are shown in figures 12, 13, and 14, respectively. These increments were determined by deducting the drag coefficients of the airfoil with the flap neutral from the drag coefficient with the flap deflected, with all other factors remaining constant.

For all three flap contours at $\alpha_o = 0^\circ$ and at positive flap deflections above 12°, the increments of drag coefficient were larger with the gap unsealed than with the gap sealed.

Comparison of figures 12 to 14 indicates that deflecting the true-contour flap generally caused the largest increment of drag; whereas deflecting the beveled-trailing-edge flap caused the least increment. When the data of figures 12 to 14 were compared on an equal lift-increment basis rather than on an equal flap-deflection basis, the true-contour flap still produced larger drag increments than the other flaps over a range of about 0.4 in Δc_l, but the difference in the increments was much less than shown in the figures.

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CONCLUSIONS

Tests have been made of the NACA 66(215)-014 airfoil equipped with true-contour, straight-contour, and beveled-trailing-edge flaps having chords equal to 30 percent of the airfoil chord. The effects that increasing the trailing-edge angle had in decreasing the lift over the airfoil trailing edge were not significantly different from the effects previously noted on conventional airfoils and are contained in the following conclusions:

1. The slope of the airfoil lift curve was largest with the sealed true-contour flap and decreased as the gap at the flap nose was opened, as the trailing-edge angle was increased, and as roughness was added to the airfoil leading edge.

2. The slope of the lift curve with controls free (zero flap hinge moment) generally increased as the trailing-edge angle increased and as roughness was added to the airfoil leading edge. The effect of the gap at the hinge line varied with trailing-edge angle and with the addition of roughness to the airfoil leading edge.

3. The effectiveness of the flap in producing lift was greatest with the true-contour flap and generally decreased as the gap at the flap nose was opened, as the trailing-edge angle was increased, and as roughness was added to the airfoil leading edge.

4. The slope of the curves of hinge moment plotted against angle of attack at a flap deflection of 0° and small angles of attack was approximately zero for the straight-contour flap, negative for the true-contour flap, and positive for the beveled-trailing-edge flap. The negative slopes of the curves of hinge moment plotted against flap deflection for all three flap contours decreased as the trailing-edge angle increased, as roughness was added to the leading edge of the airfoil, and, for the straight-contour and beveled-trailing-edge flaps, as the gap at the flap nose was unsealed.

5. When the lift was varied by changing the angle of attack at zero flap deflection, the aerodynamic center of the smooth airfoil with a sealed gap moved forward as

the trailing-edge angle was increased. Unsealing the gap had little effect on the aerodynamic center; whereas the addition of leading-edge roughness moved the aerodynamic center forward 1 or 2 percent of the airfoil chord. At constant angle of attack the aerodynamic center of lift caused by flap deflection also tended to move forward as the trailing-edge angle was increased. Unsealing the gap or adding roughness at the airfoil leading edge tended to move the aerodynamic center rearward for the true-contour flap and forward for the beveled-trailing-edge flap.

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REFERENCES

1. Gillis, Clarence L., and Lockwood, Vernard E.: Wind-Tunnel Investigation of Control-Surface Characteristics. XIII - Various Flap Overhangs Used with a 30-Percent-Chord Flap on an NACA 66-009 Airfoil. NACA ACR No. 3G20, July 1943.

2. Sears, Richard I., and Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. II - A Large Aerodynamic Balance of Various Nose Shapes with a 30-Percent-Chord Flap on an NACA 0009 Airfoil. NACA A.R.R., Aug. 1941.

3. Sears, Richard I., and Gillis, Clarence L.: Wind-Tunnel Investigation of Control-Surface Characteristics. VIII - A Large Aerodynamic Balance of Two Nose Shapes Used with a 30-Percent-Chord Flap on an NACA 0015 Airfoil. NACA A.R.R., July 1942.

4. Jones, Robert T., and Ames, Milton B., Jr.: Wind-Tunnel Investigation of Control-Surface Characteristics. V - The Use of a Beveled Trailing Edge to Reduce the Hinge Moment of a Control Surface. NACA A.R.R., March 1942.

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5. Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Control-Surfaces Characteristics. X - A 30-Percent-Chord Plain Flap with Straight Contour on the NACA 0015 Airfoil. NACA A.R.R., Sept. 1942.

6. Purser, Paul E., and Gillis, Clarence L.: Preliminary Correlation of the Effects of Beveled Trailing Edges on the Hinge-Moment Characteristics of Control Surfaces. NACA CB No. 3E14; May 1943.

7. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. Rep. No. 387, NACA, 1931.

8. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Supplement (loose-leaf) to NACA Advance Confidential Report, Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence. NACA, March 1942.

9. Sears, Richard I.: Wind-Tunnel Data on the Aerodynamic Characteristics of Airplane Control Surfaces. NACA ACR No. 3L08; Dec. 1943.

10. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. Rep. No. 721, NACA, 1941.

TABLE I

ORDINATES FOR NACA 66(215)-014 AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
0	0	0
.5	1.036	-1.036
.75	1.240	-1.240
1.25	1.535	-1.535
2.5	2.080	-2.080
5.0	2.880	-2.880
7.5	3.506	-3.506
10	4.048	-4.048
15	4.904	-4.904
20	5.566	-5.566
25	6.081	-6.081
30	6.470	-6.470
35	6.748	-6.748
40	6.920	-6.920
45	6.995	-6.995
50	6.962	-6.962
55	6.807	-6.807
60	6.497	-6.497
65	5.978	-5.978
70	5.224	-5.224
75	4.342	-4.342
80	3.375	-3.375
85	2.375	-2.375
90	1.389	-1.389
95	.523	-.523
100	.095	-.095
L.E. radius: 1.206		

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TABLE II

PARAMETER VALUES OF FLAPS OF 0.30c TESTED ON THE NACA 66(215)–014 AIRFOIL IN THE NACA 4- BY 6-FOOT VERTICAL TUNNEL

Parameters	Leading-edge surface	True-contour flap; $\phi = 18^\circ$		Straight-contour flap; $\phi = 19.3^\circ$		Beveled-trailing-edge flap; $\phi = 30^\circ$	
		Gap, sealed	Gap, 0.002c	Gap, sealed	Gap, 0.002c	Gap, sealed	Gap, 0.002c
$\left(\frac{\partial \alpha_0}{\partial \delta_f}\right)_{c_l}$	Smooth	–0.58	–0.59	–0.58	–0.53	–0.56	–0.46
	Rough	–.56	–.53	–.55	–.46	–.48	–.42
$\left(\frac{\partial c_l}{\partial \alpha_0}\right)_{\delta_f}$	Smooth	.098	.094	.090	.085	.084	.079
	Rough	.092	.088	.084	.081	.080	.077
$\left(\frac{\partial c_l}{\partial \alpha_0}\right)_{ch_f=0}$	Smooth	.064	.061	.087	.085	.189	.282
	Rough	.059	.062	.091	.091	.358	Divergent
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\delta_f}$	Smooth	.005	.003	.028	.032	.045	.058
	Rough	.013	.011	.038	.041	.062	.062
$\left(\frac{\partial c_m}{\partial c_l}\right)_{\alpha_0}$	Smooth	–.160	–.183	–.172	–.184	–.159	–.150
	Rough	–.189	–.213	–.174	–.180	–.132	–.125
$\left(\frac{\partial ch_f}{\partial \alpha_0}\right)_{\delta_f}$	Smooth	–.0081	–.0088	–.0005	0	.0049	.0056
	Rough	–.0079	–.0077	.0008	.0010	.0057	.0058
$\left(\frac{\partial ch_f}{\partial \delta_f}\right)_{\alpha_0}$	Smooth	–.0134	–.0146	–.0076	–.0059	–.0022	–.0010
	Rough	–.0122	–.0140	–.0052	–.0036	–.0008	.0010

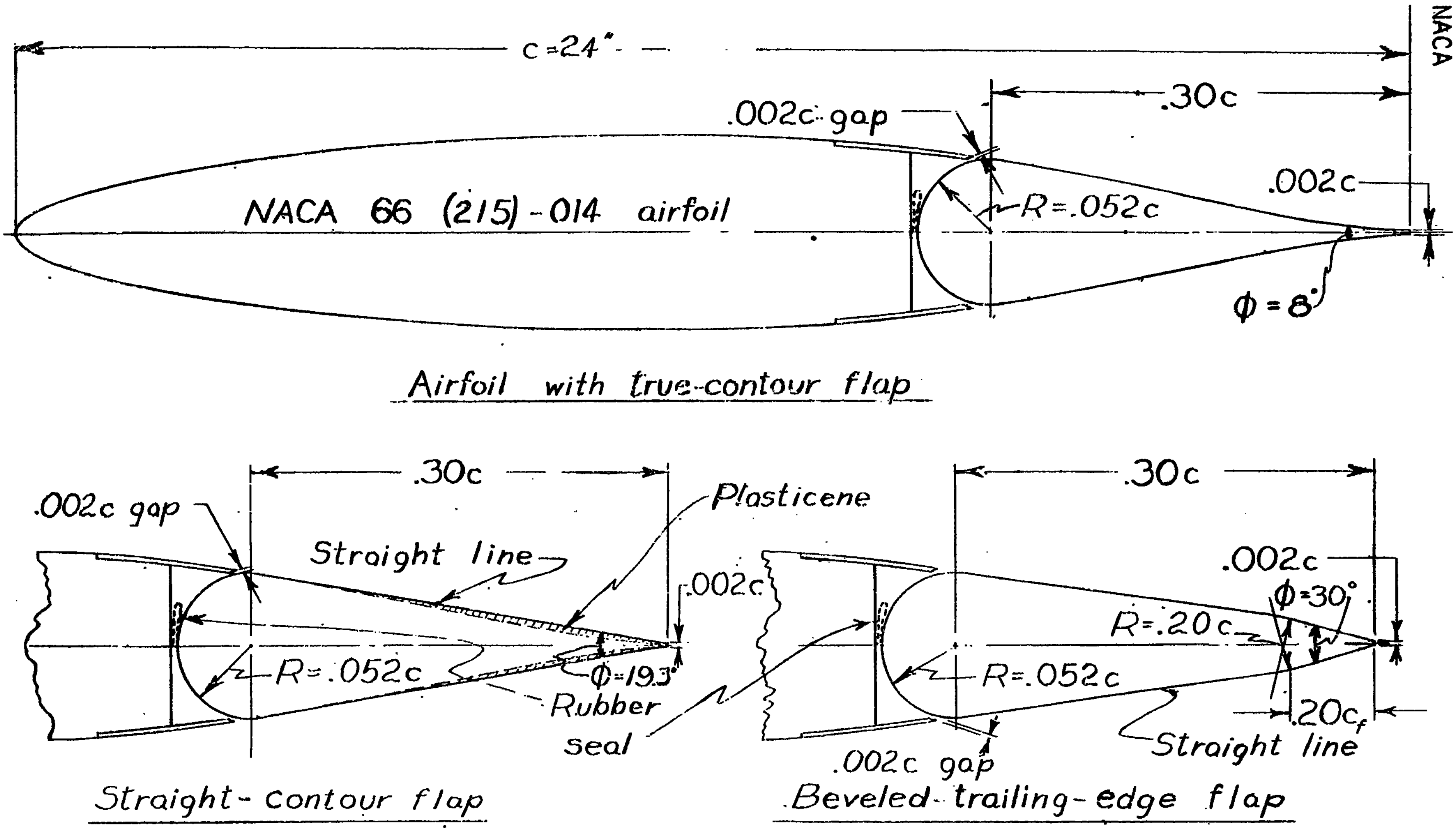

Figure 1.- Details of flaps tested on NACA 66 (215)-014 airfoil.

NACA Fig. 2a

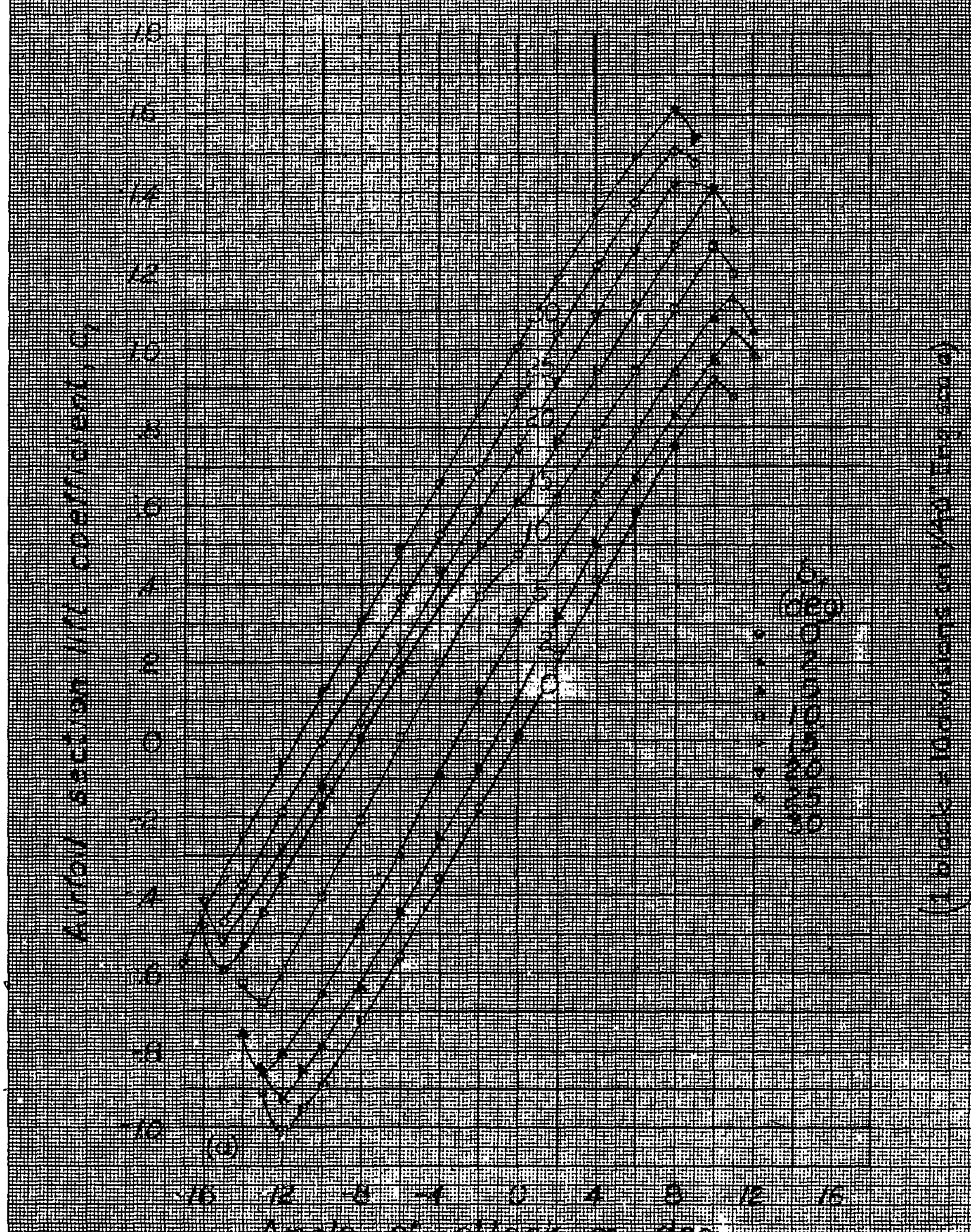

Figure 2.- Aerodynamic section characteristics of an NACA 65 (215)-014 airfoil having a 0.30c true-contour flap. Gap, 0.002c.

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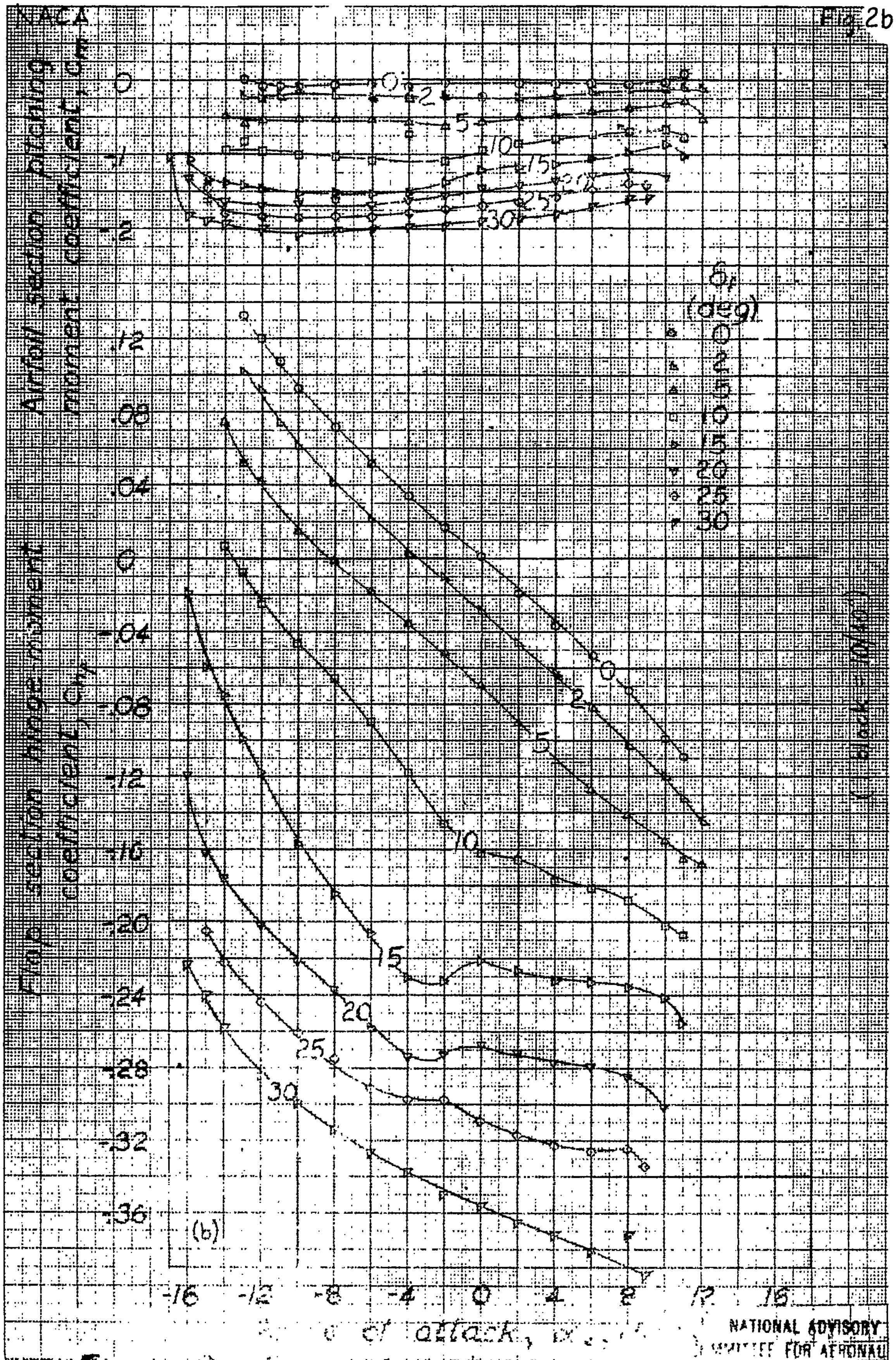


Figure 2.- Concluded.

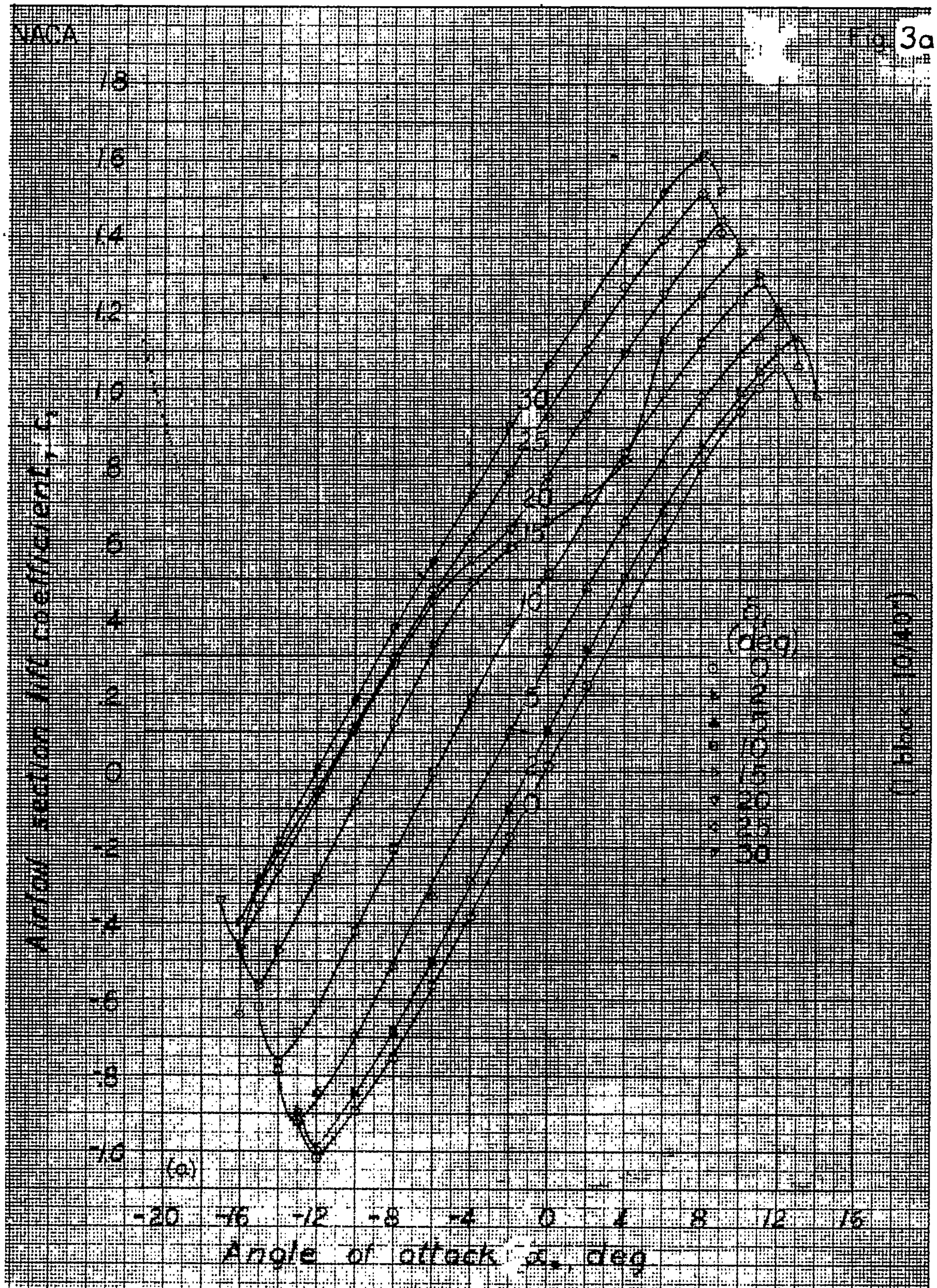
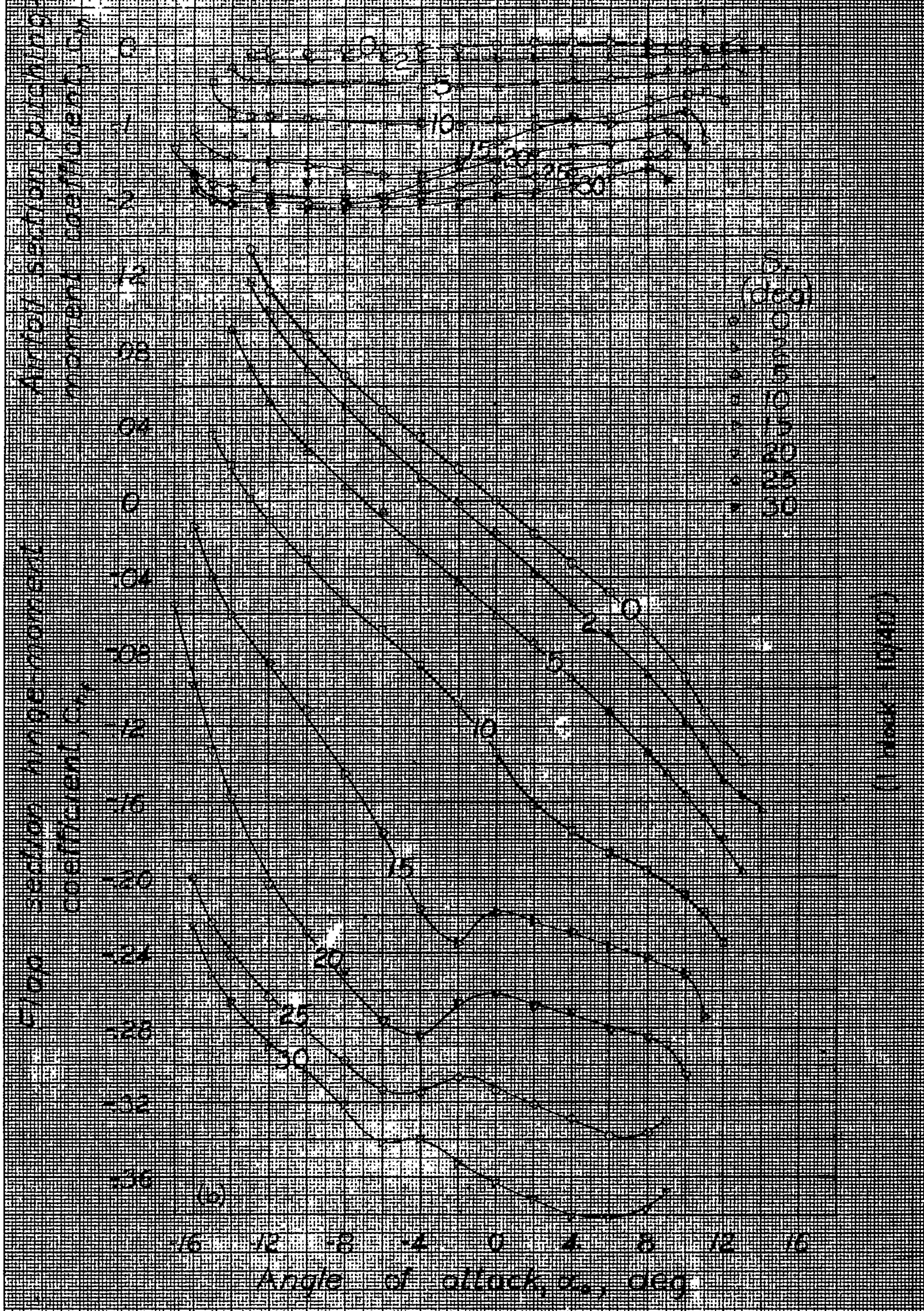


Figure 3.-Aerodynamic section characteristics of an NACA 66(215)-014 airfoil having a 0.30c true-contour flap. Gap sealed



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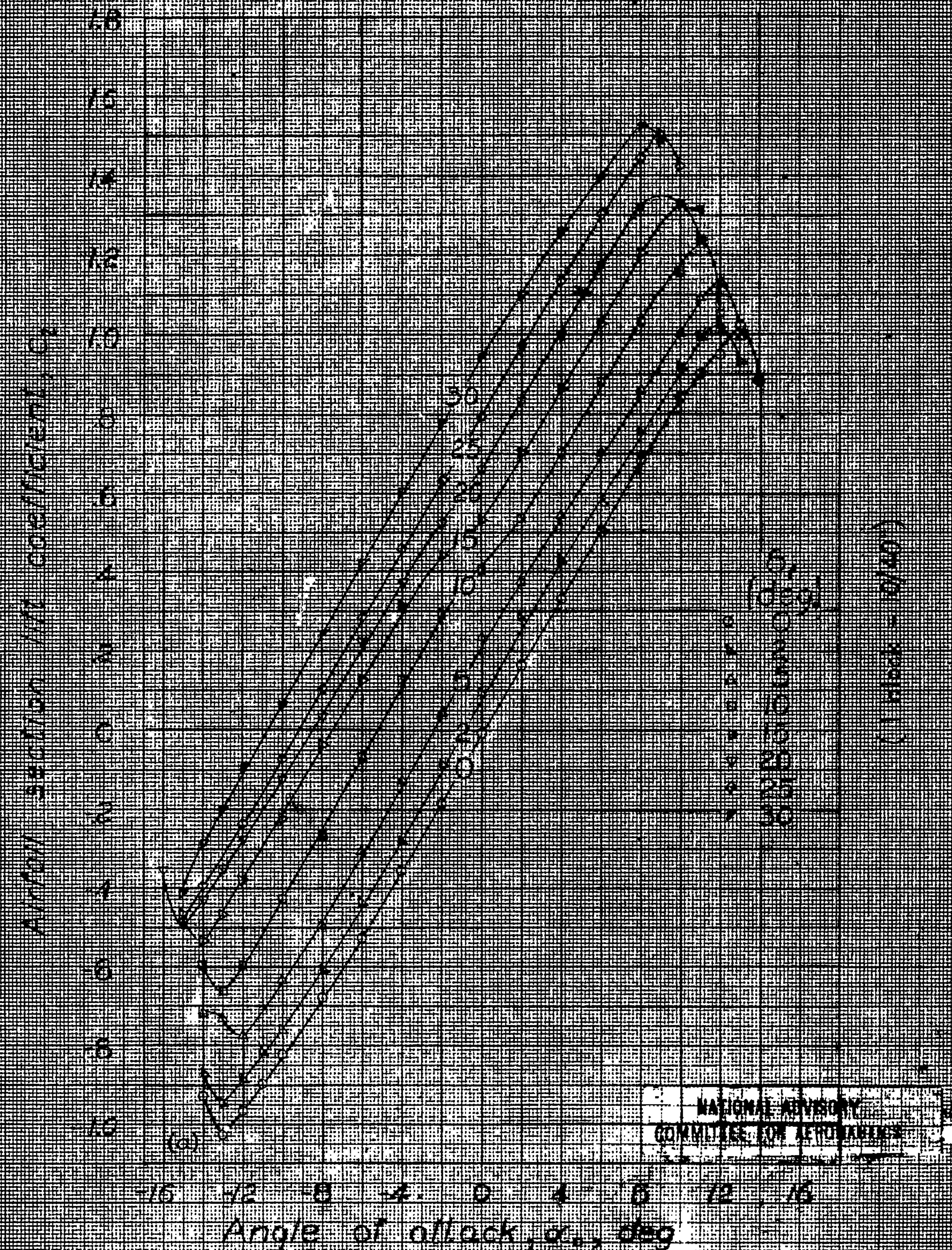

Figure 4- Aerodynamic section characteristics of an NACA 66 (215)-014 airfoil having a 0.30c straight-contour flap. Gap, 0.002c.

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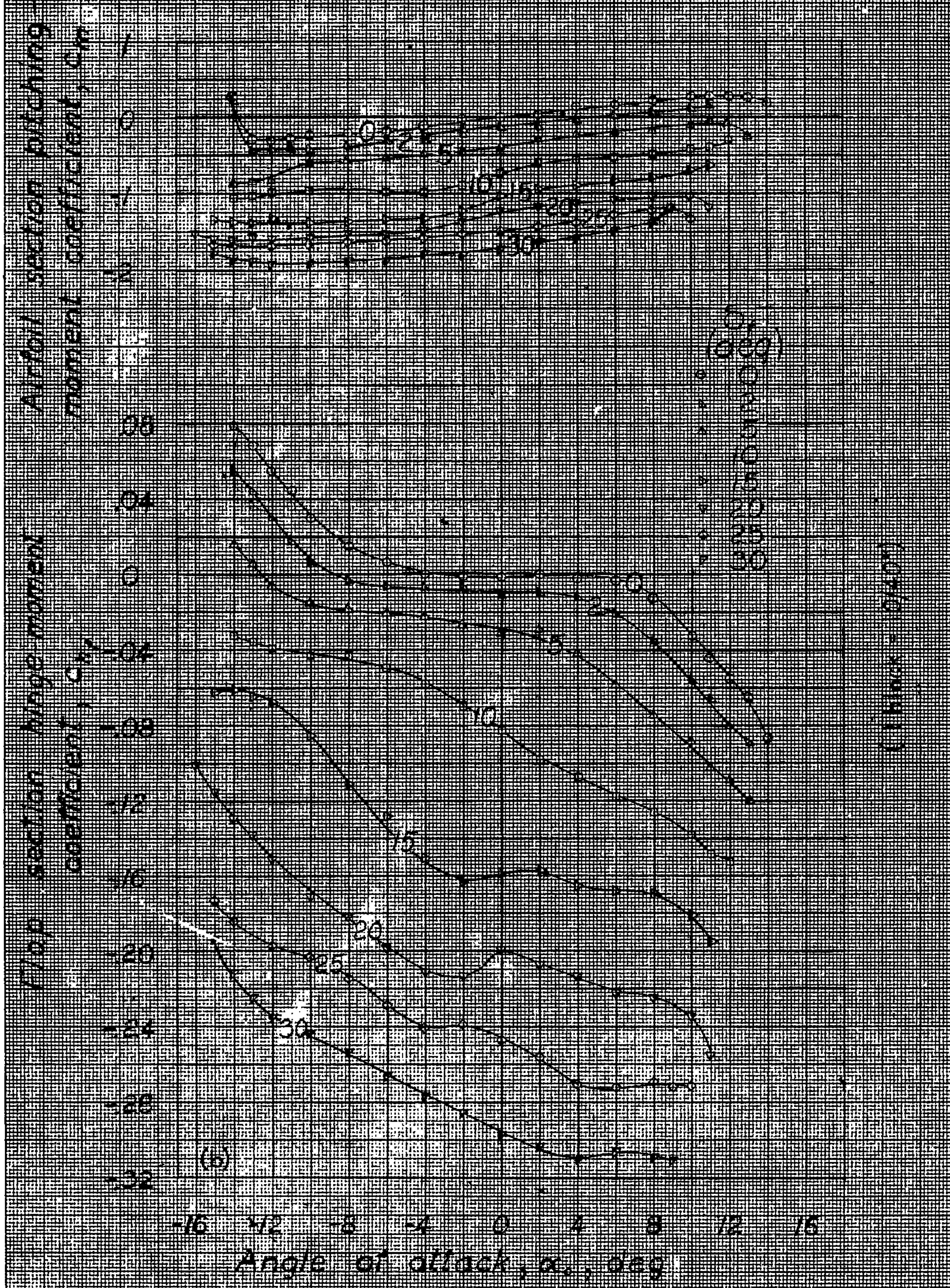

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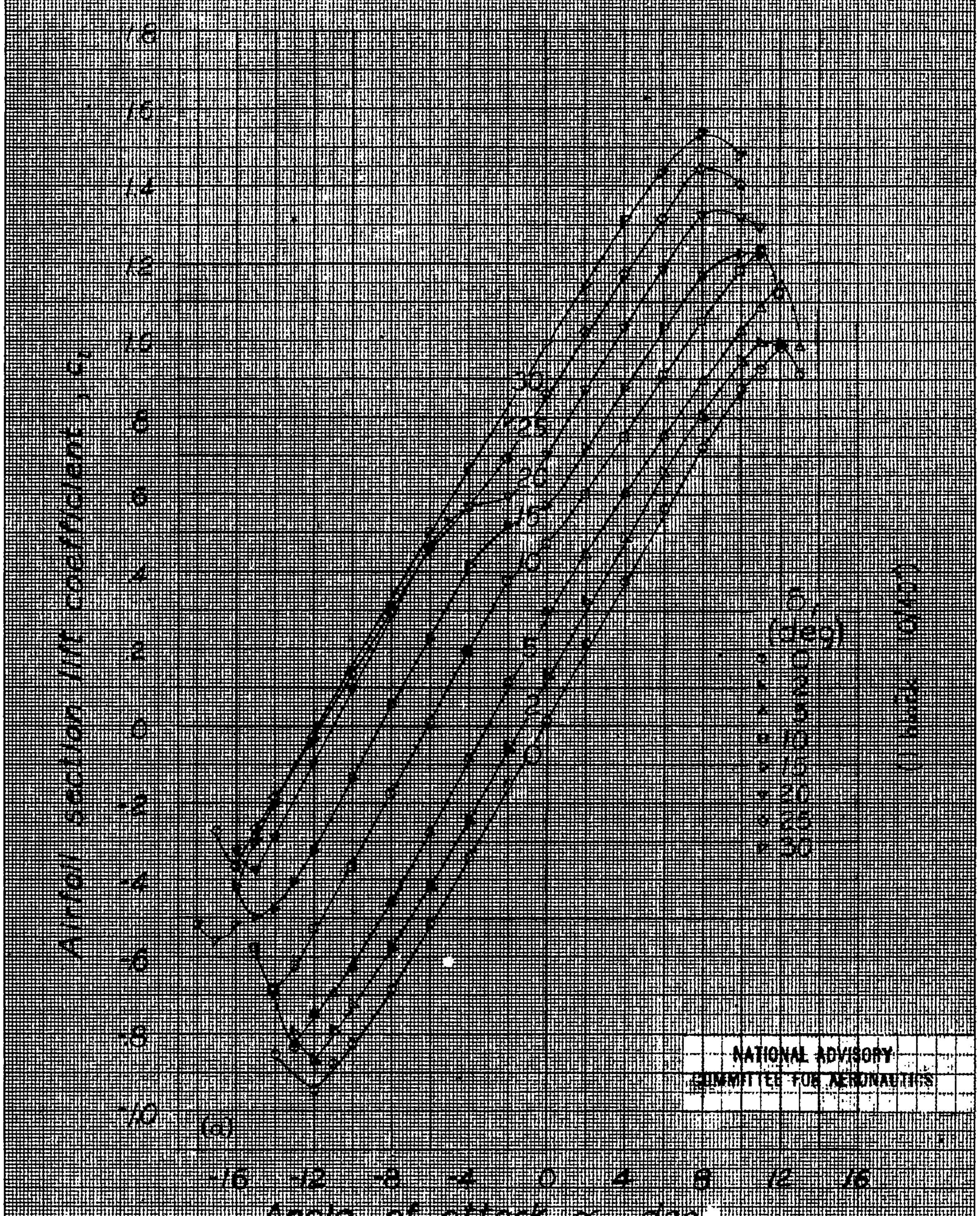

Figure 5.- Aerodynamic section characteristics of an NACA 66 (215)-014 airfoil having a 0.30c straight-contour flap. Gap sealed.

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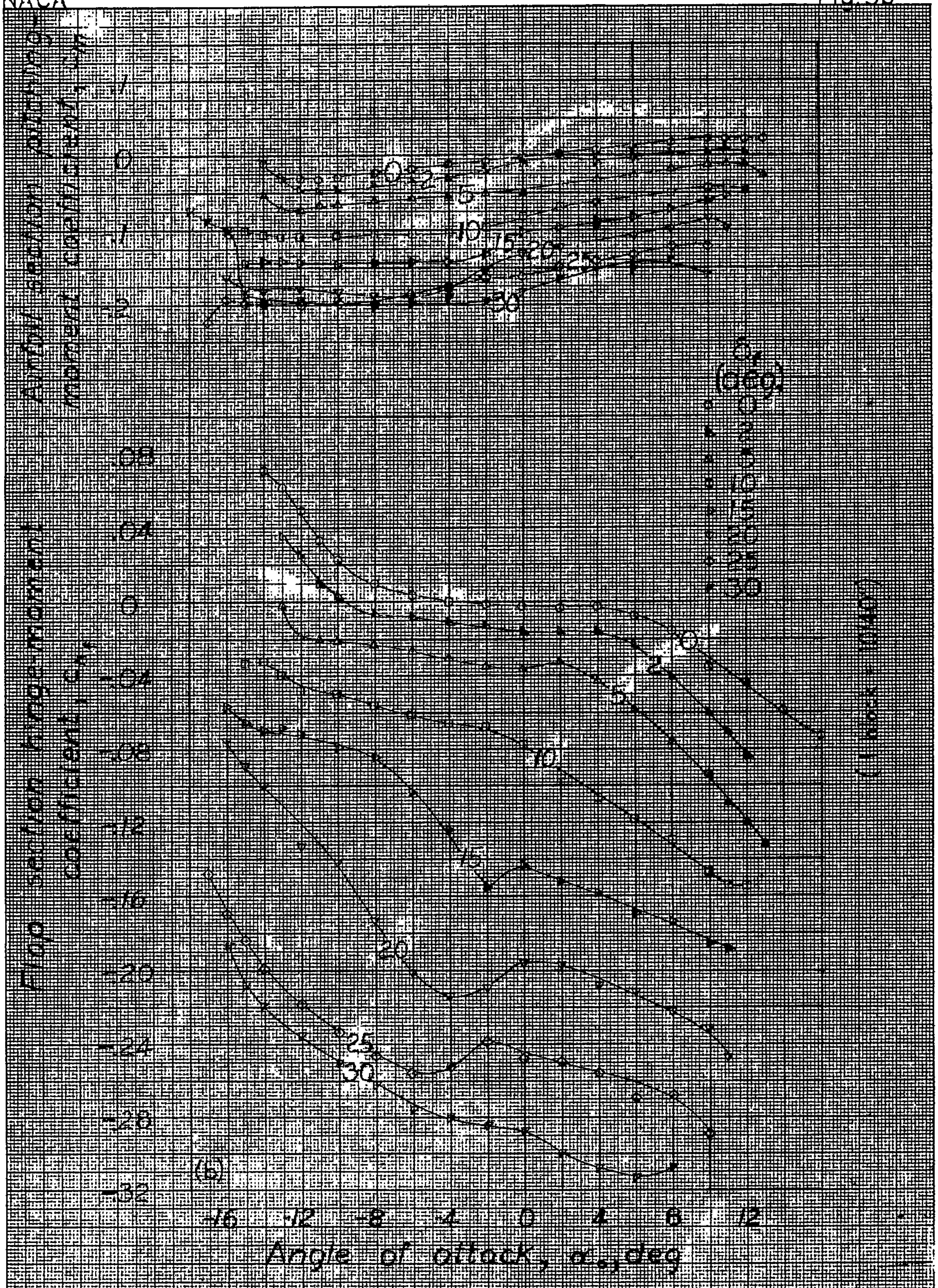

Figure 5.- Concluded.

(b)

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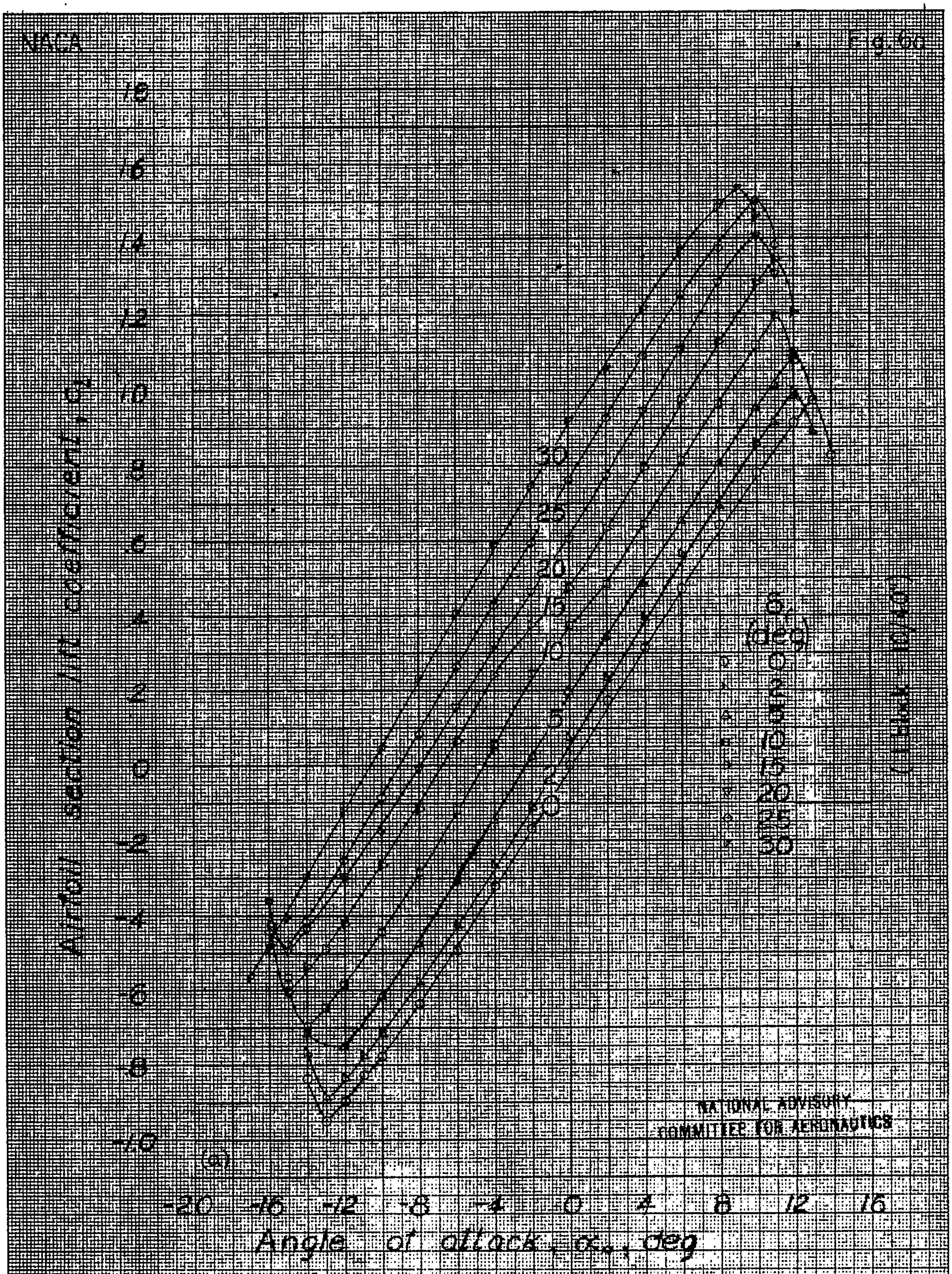

Figure 6.- Aerodynamic section characteristics of an NACA 66 (215)-014 airfoil having a 0.30c beveled-trailing-edge flap. Gap, 0.002c.

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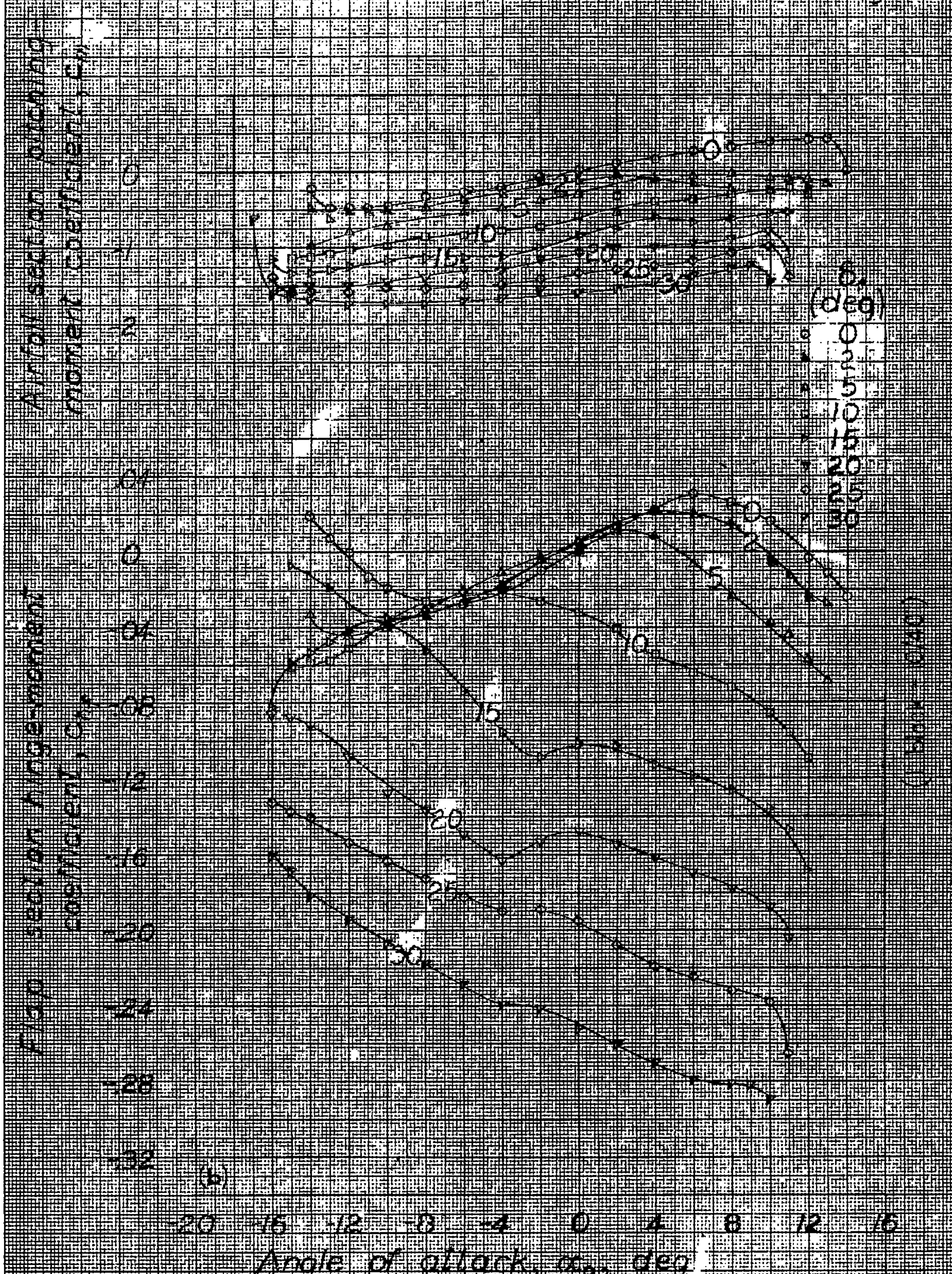

Figure 6-Concluded.

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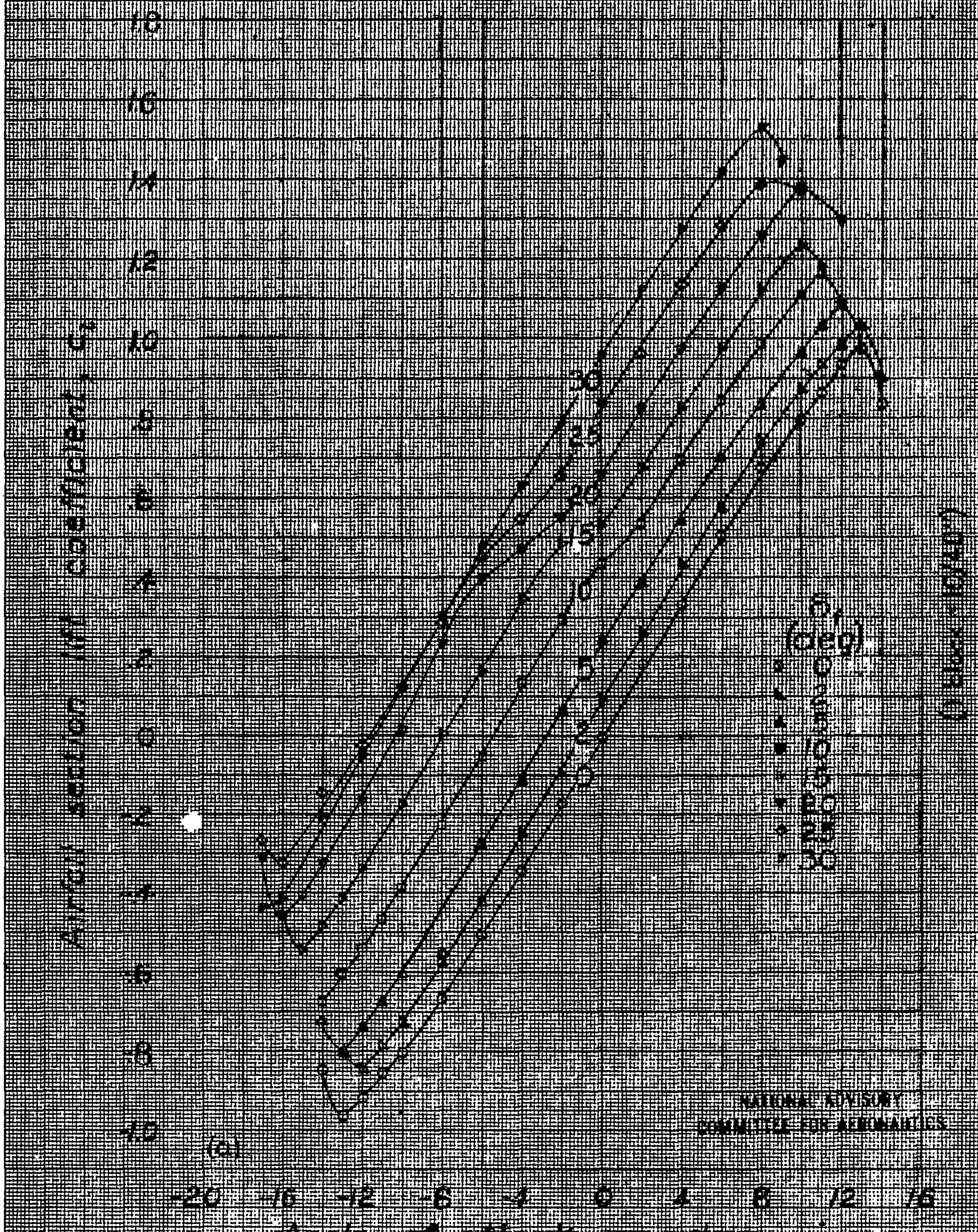

Figure 7.- Aerodynamic section characteristics of an NACA 66 (215)014 airfoil having a 0.30c beveled-trailing-edge flap. Gap sealed.

(a)

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NACA Fig. 7b

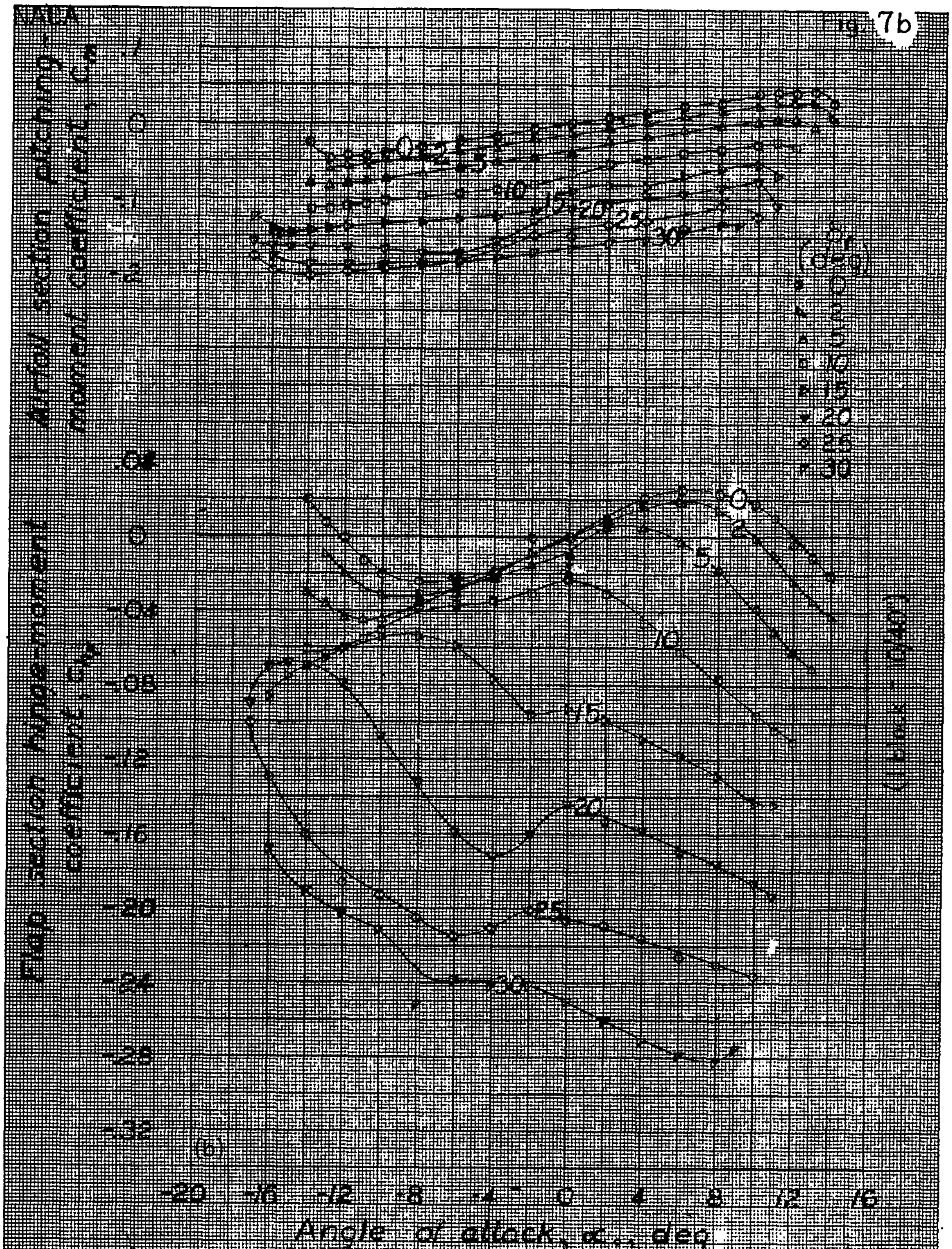

Figure 7.- Concluded.

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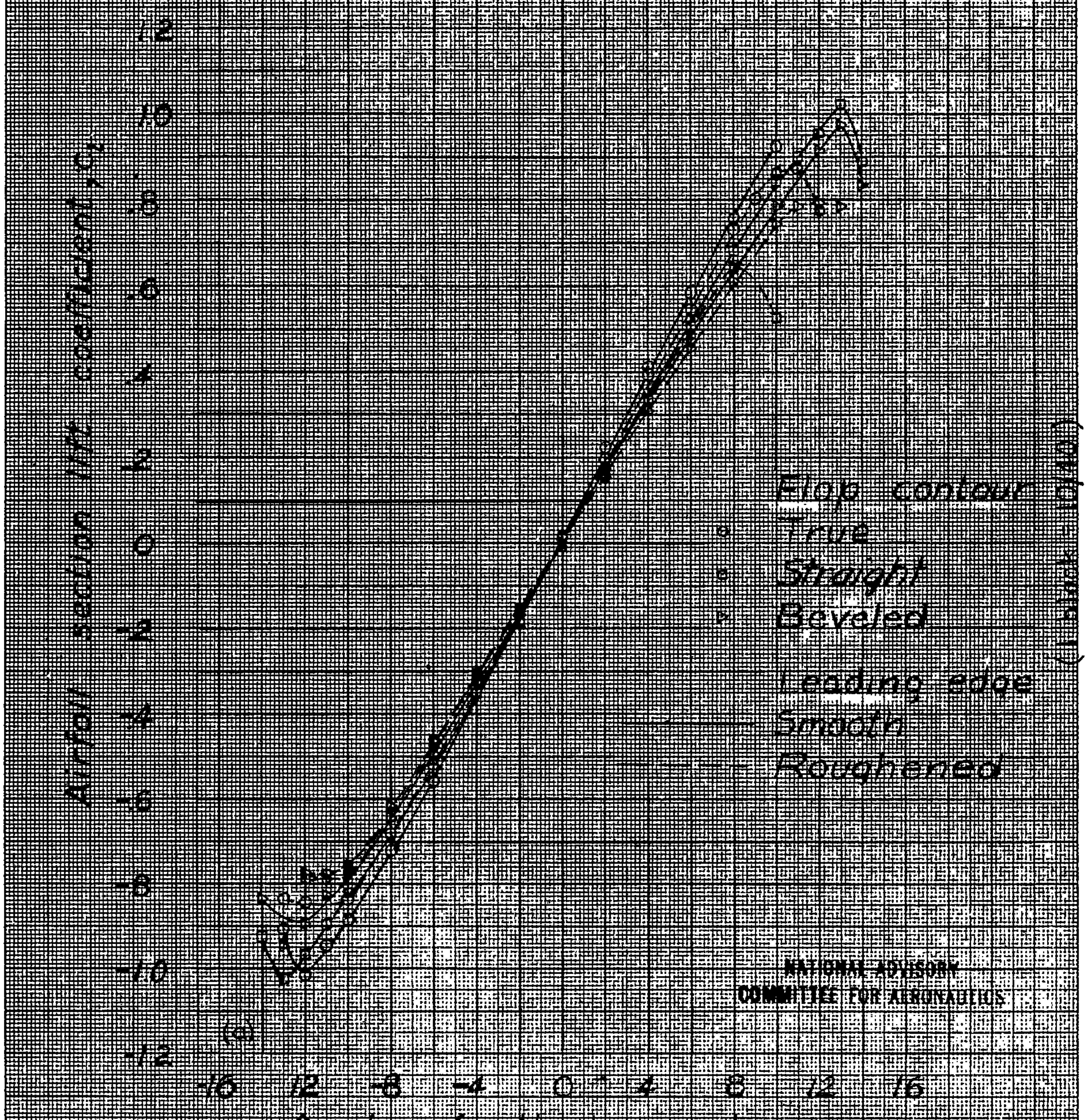

Figure 8.-Variation of airfoil aerodynamic section characteristics with angle of attack for 0.30c plain, straight, and beveled-trailing-edge flaps on NACA 66 (215)-014 airfoil with smooth and roughened leading edge. Gap, 0.002c; δ_f = 0°.

(a)

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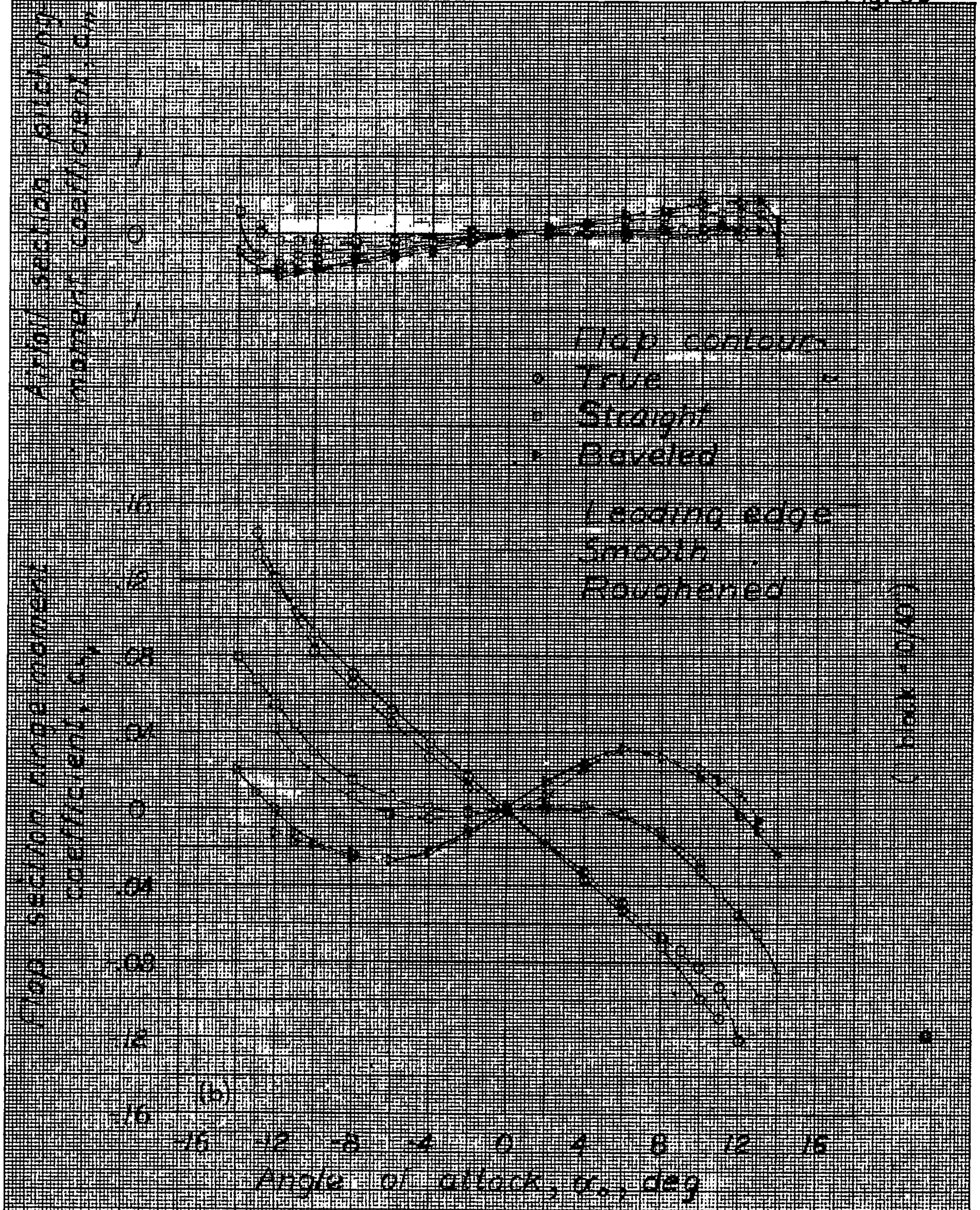

Figure 8-Concluded.

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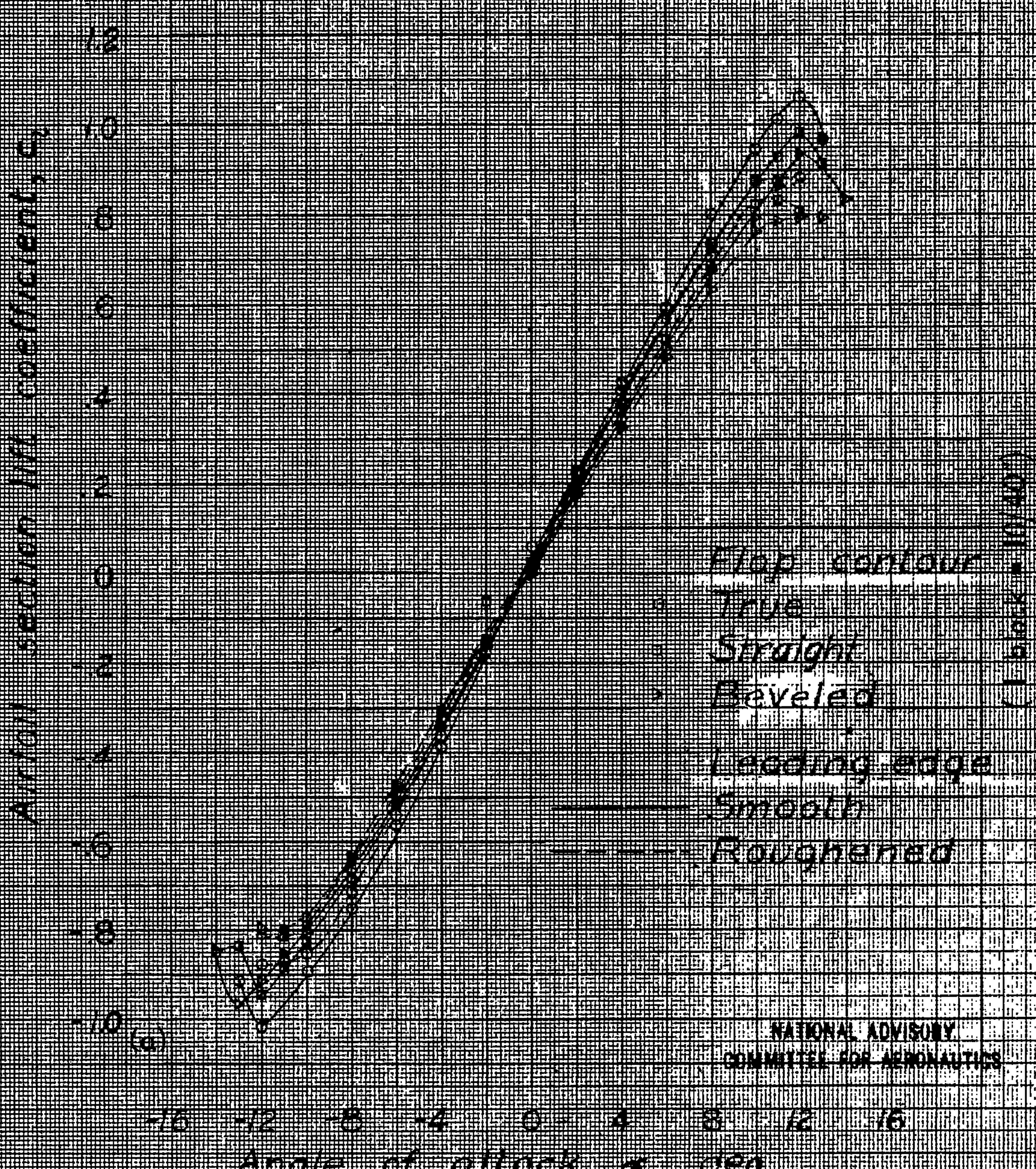

Figure 9.- Variation of airfoil aerodynamic section characteristics with angle of attack for 0.30c plain, straight, and beveled-trailing edge flaps on NACA 66 (215)-014 airfoil with smooth and roughened leading edge. Gap sealed, $\delta_f = 0$.

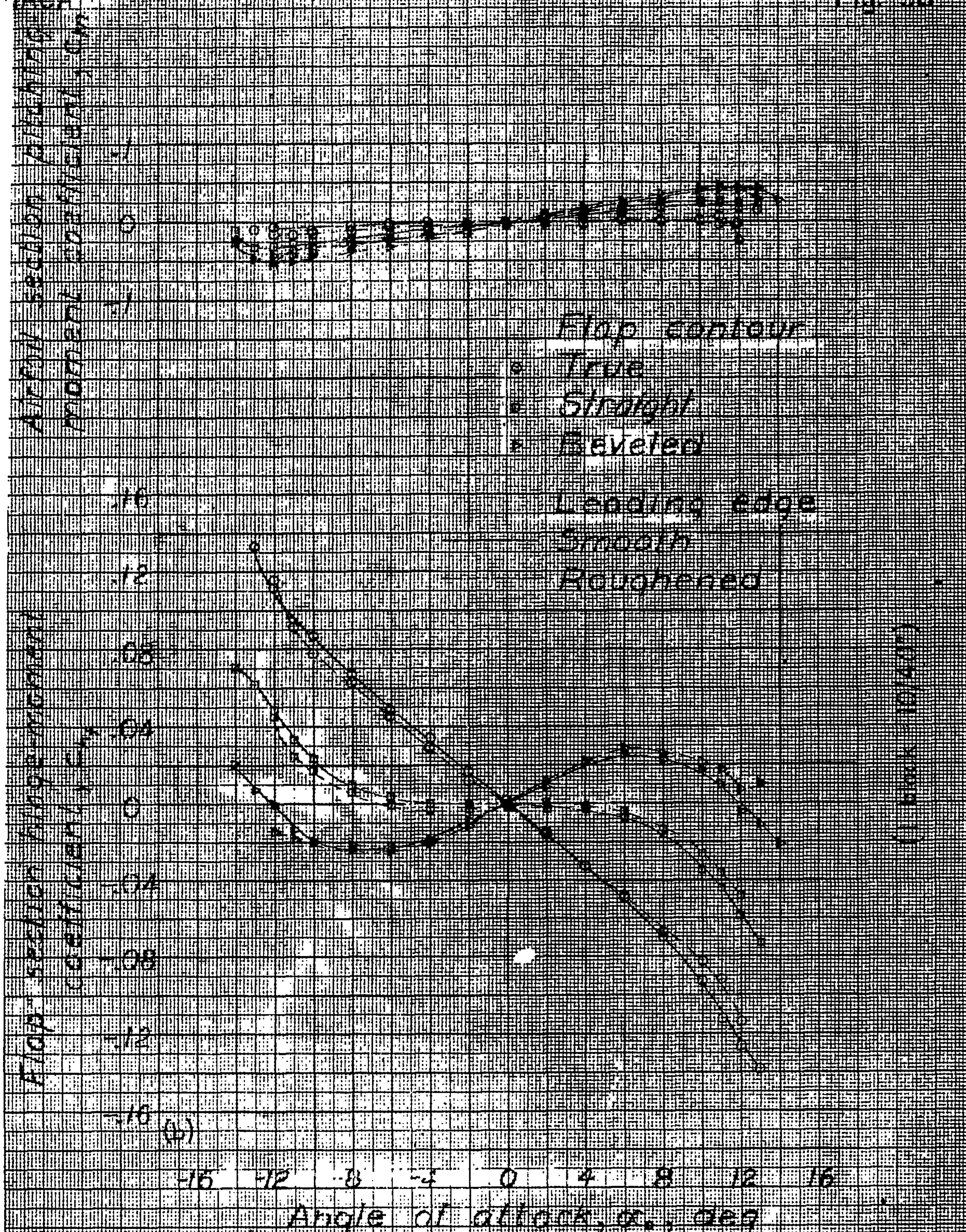

Figure 9.- Concluded.

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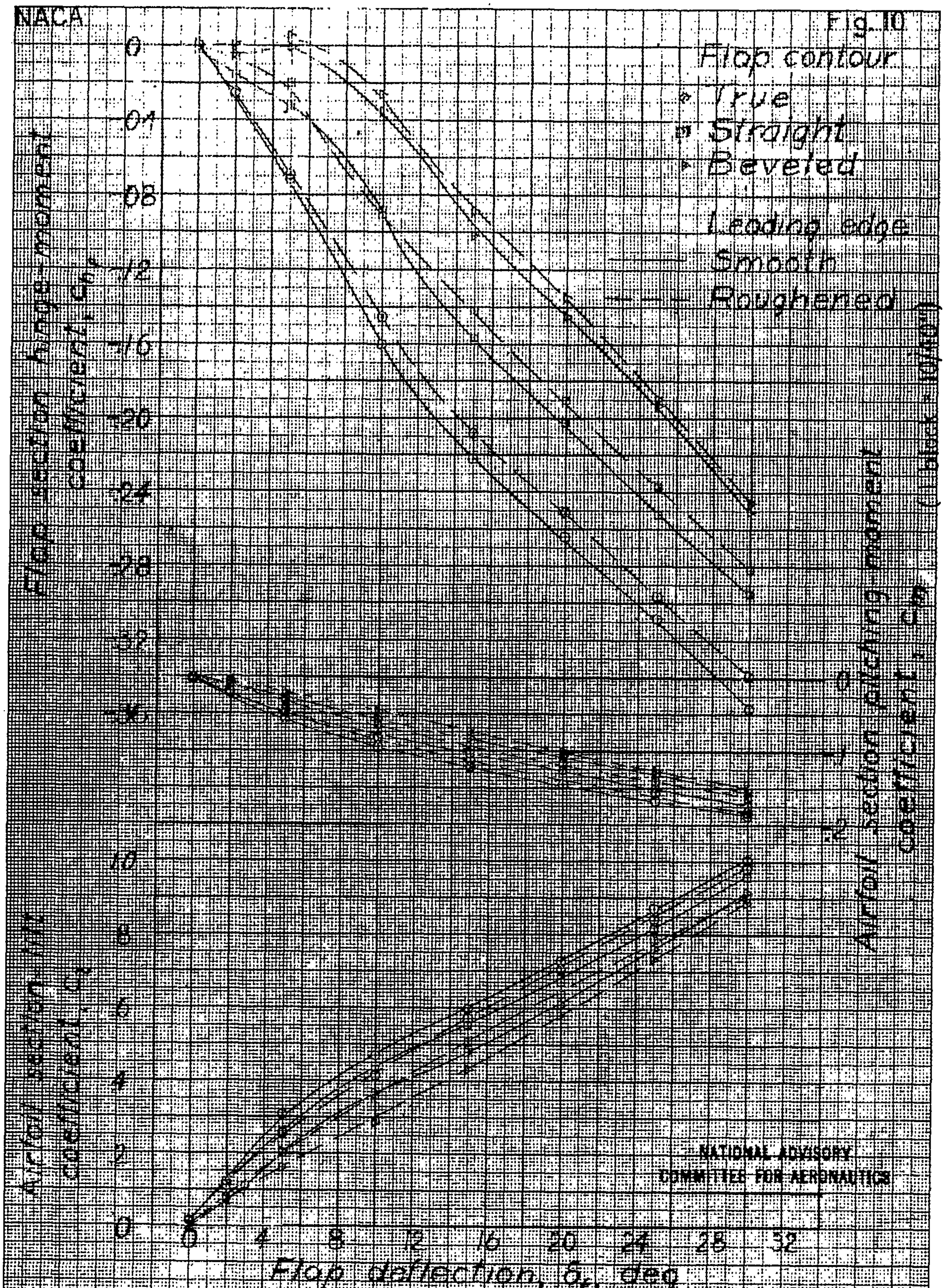

Figure 10. Variation of aerodynamic section characteristics with flap deflection for 0.30c plain, straight and beveled trailing edge flaps on NACA 66(215)014 airfoil, with smooth and roughened leading edge. Gap, 0.002c; $\alpha_o = 0°$.

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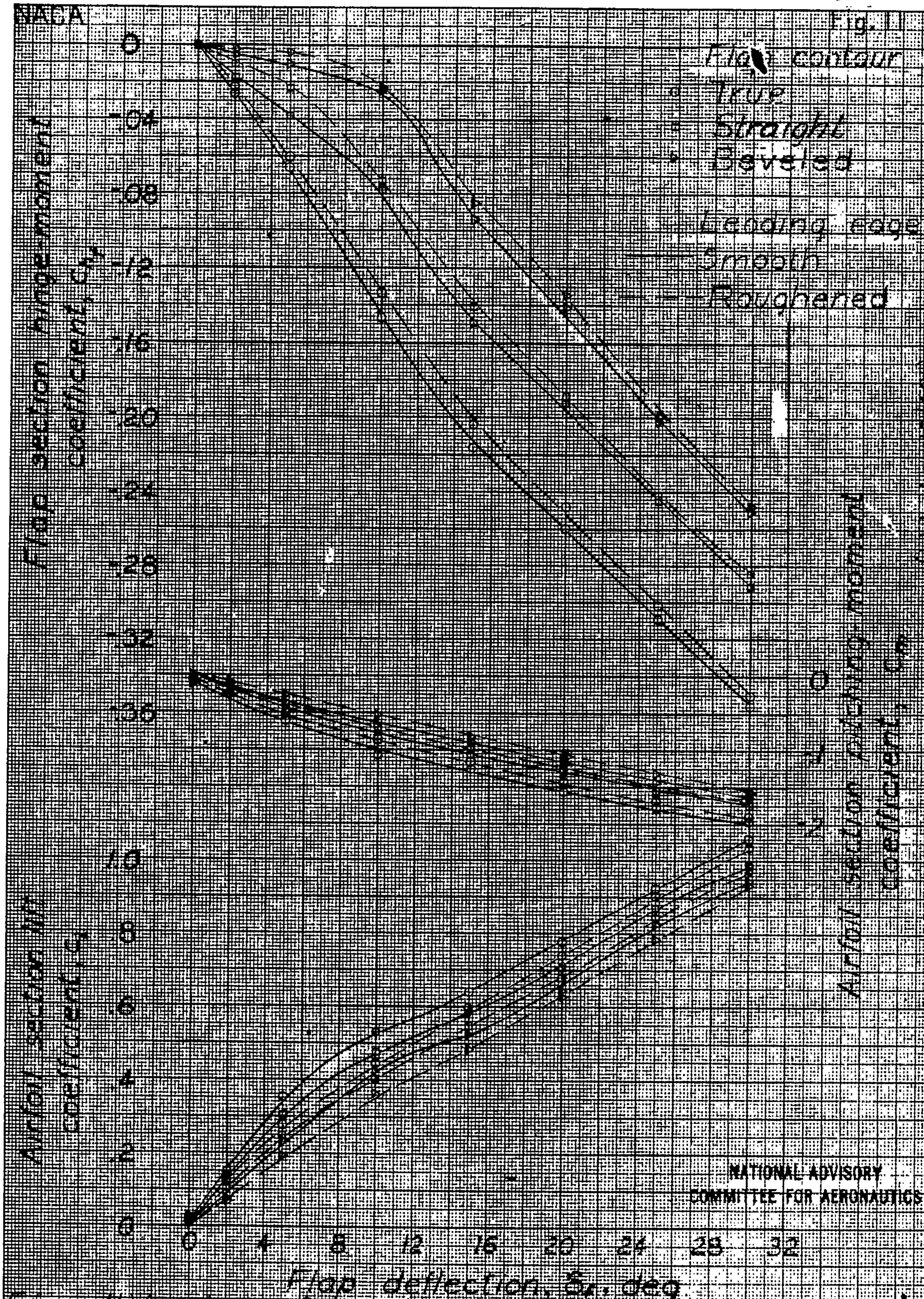

Figure 11-Variation of aerodynamic section characteristics with flap deflection for 0.30c plain, straight and beveled-trailing-edge flaps on NACA 66 (215)-014 airfoil with smooth and roughened leading edge. Gap sealed; $\alpha_0 = 0°$.

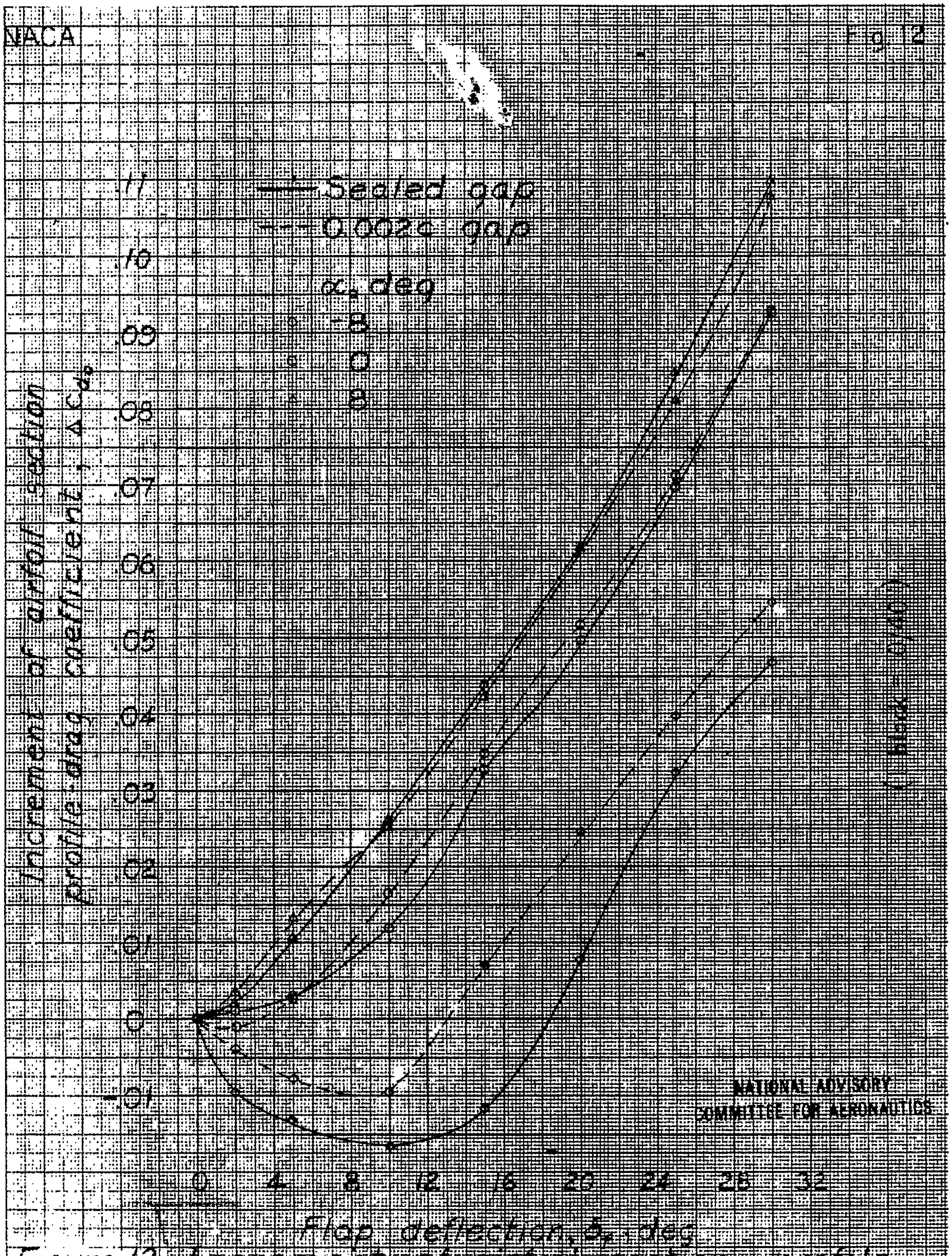

Figure 12.- Increment of airfoil section profile-drag coefficient caused by deflection of a 0.30c true-contour flap, $\phi = 8^\circ$, with gap sealed and with 0.002c gap.

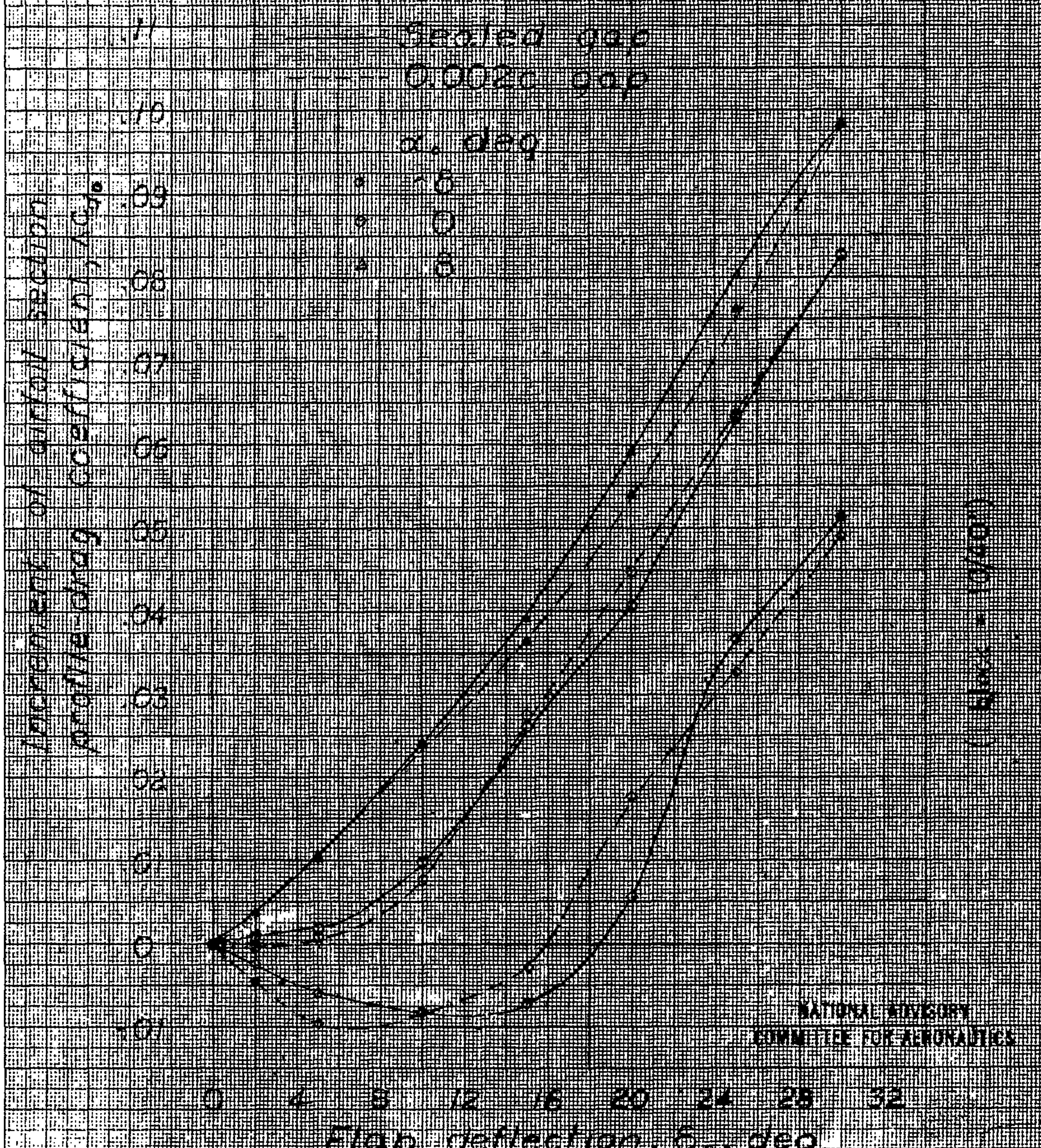

Figure 13.-Increment of airfoil section profile-drag coefficient caused by deflection of a 0.30c straight-contour flap, ϕ=19.3°, with gap sealed and with 0.002c gap.

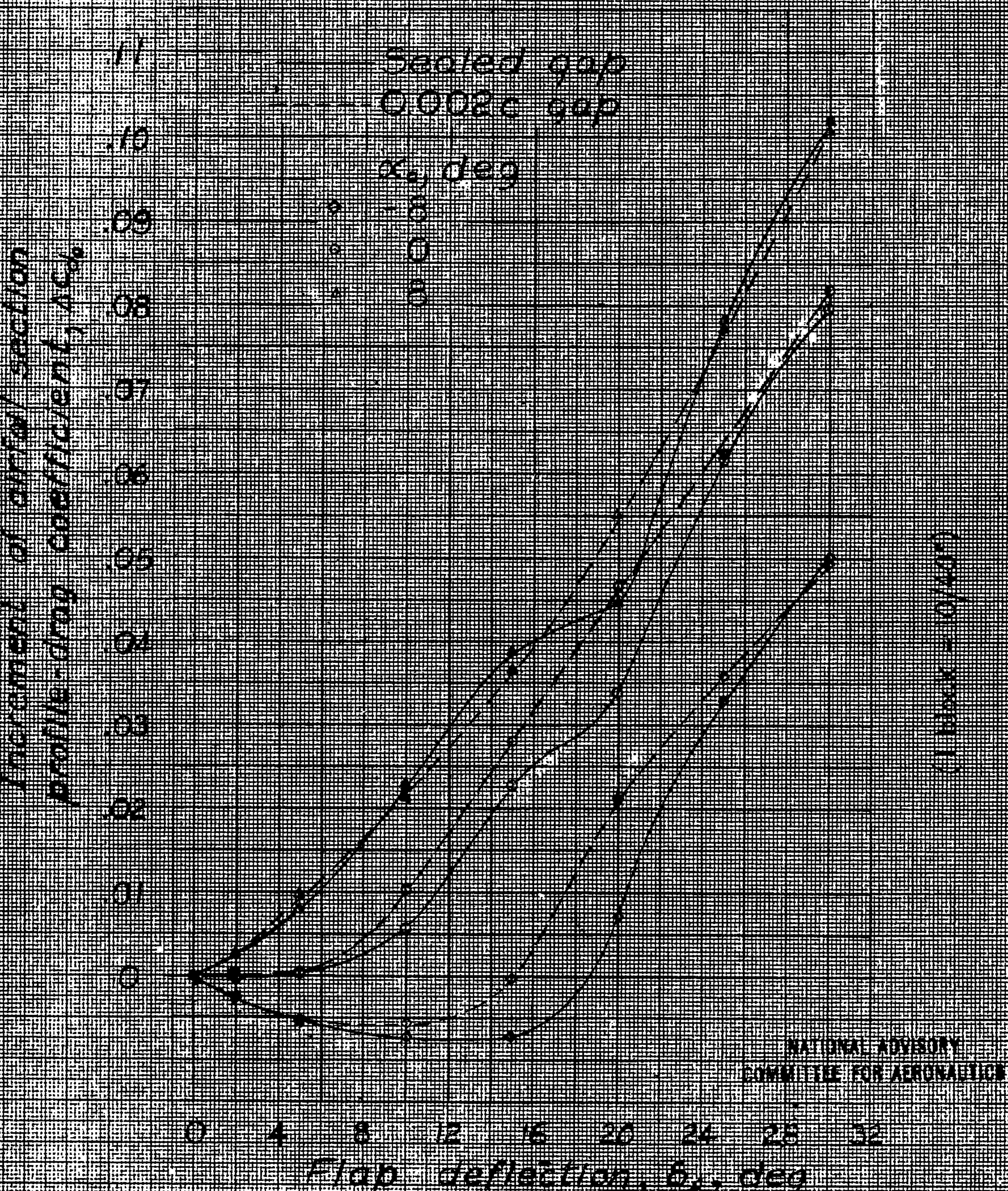

Figure 14.- Increment of airfoil section profile-drag coefficient caused by deflection of a 0.30c beveled-trailing-edge flap, $\phi = 30°$, with gap sealed and with 0.002c gap.

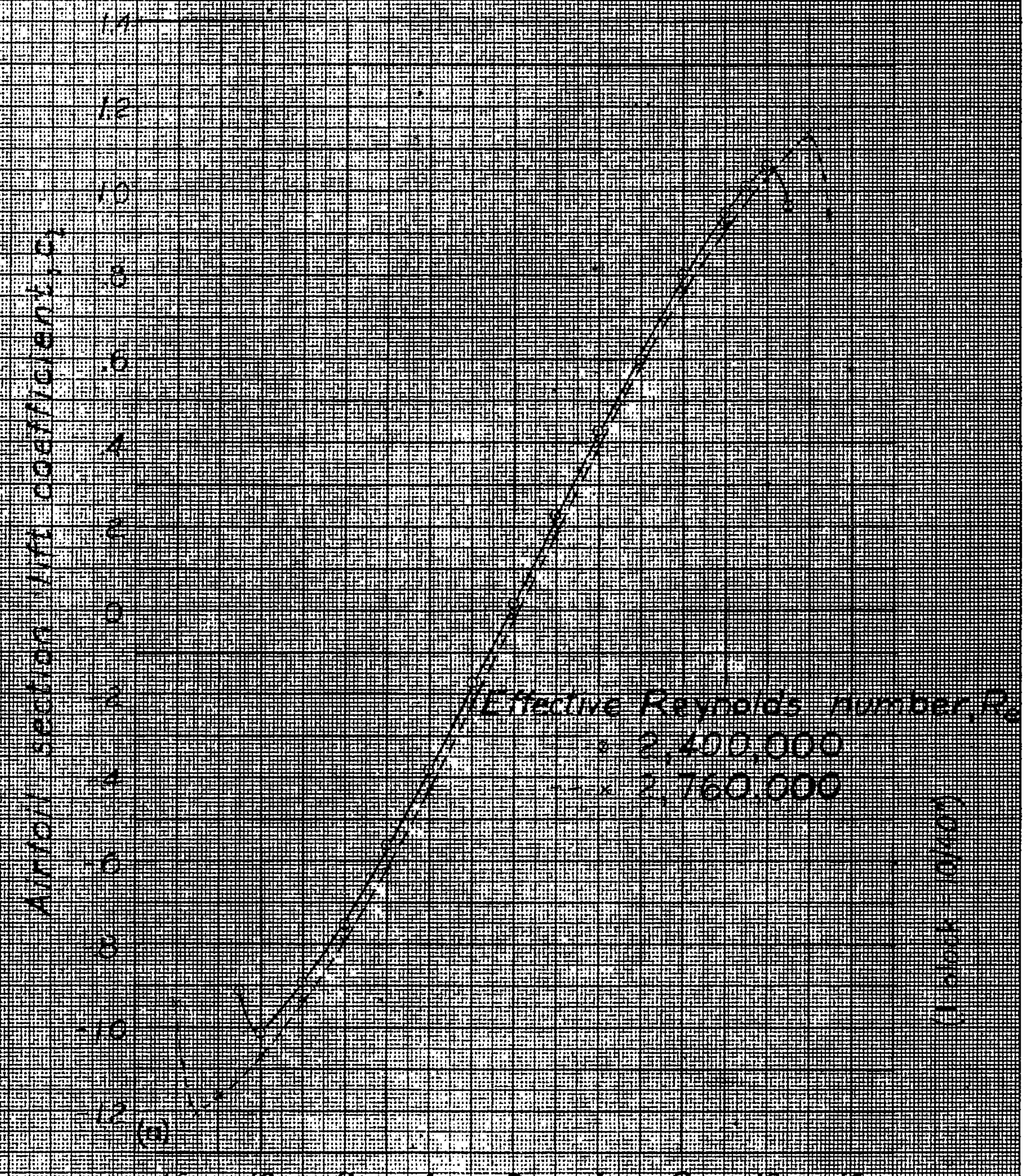

Figure 15.- Reynolds number effect on the aerodynamic section characteristics of the NACA 66,(215)-014 airfoil with a 0.30c true-contour flap at $\delta_f = 0°$. Gap sealed.

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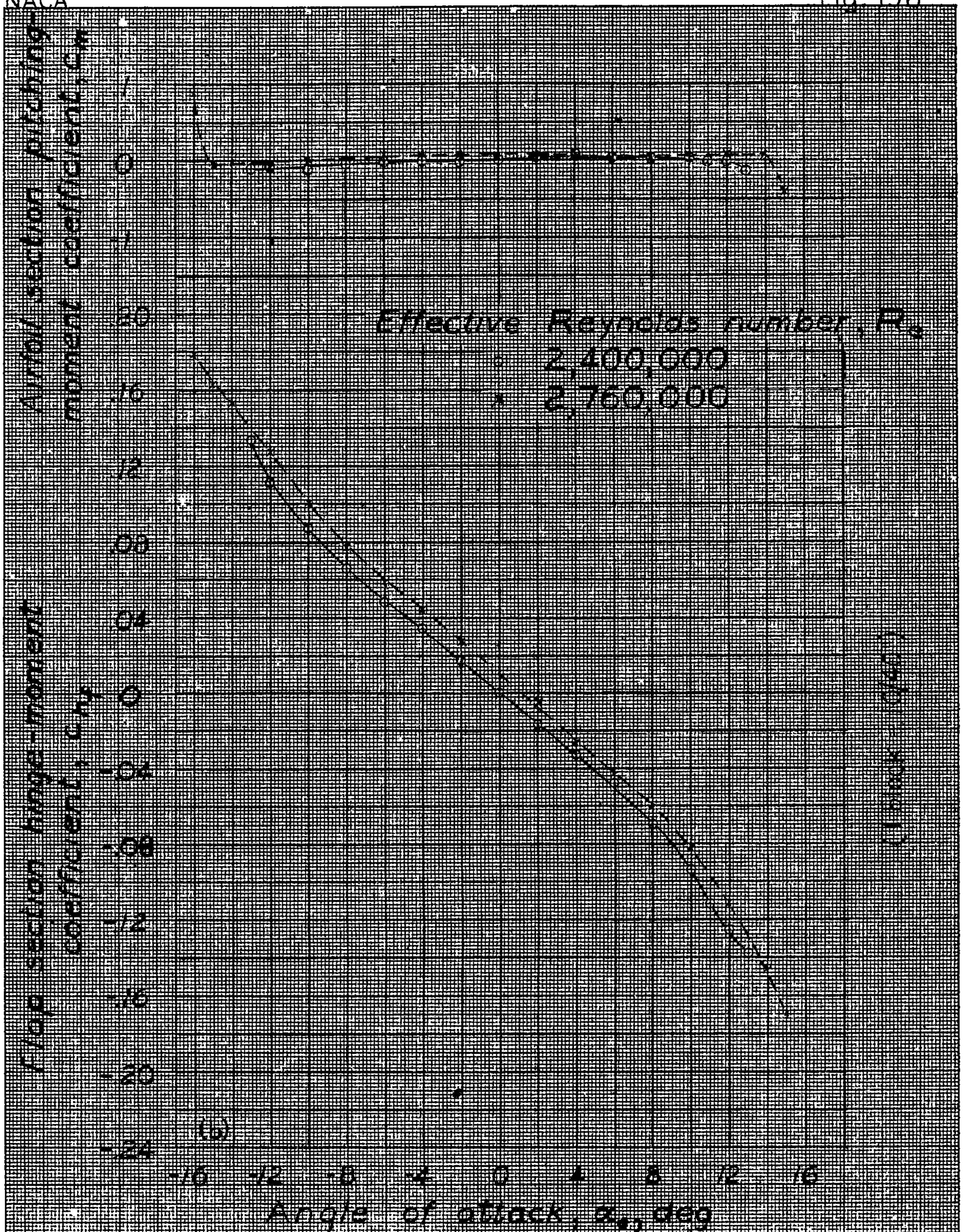

Figure 15.-Concluded.

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(b)

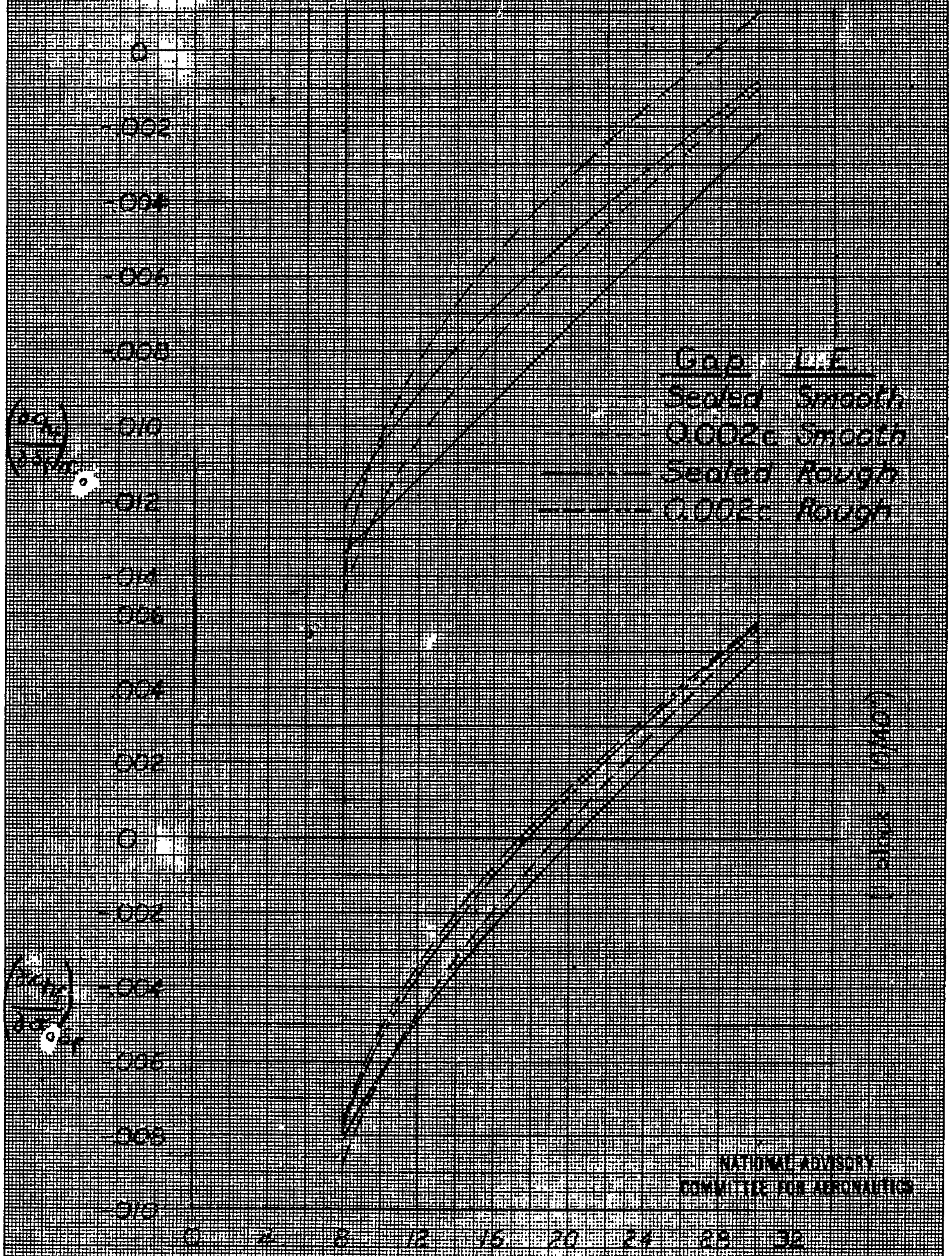

Figure 16.- Variation of the slopes of the hinge-moment curves with trailing-edge angle for a plain flap of 0.30c on the NACA 66(215)-014 airfoil.

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